THE ENGINEER

A Seven-Day Journal

The Institution of Electrical Engineers' Dinner

THE annual dinner of the Institution of Electrical Engineers was held at Grosvenor House, London, on Thursday, February 28th. After the loyal toast had been duly honoured the toast of "The Institution" was proposed by His Grace the Archbishop of Canterbury, who said that although he knew little of the technicalities of electrical engineering, he was glad to have evidence that the profession was conscious of the dangers of becoming too self-centred. He abominated over-specialisation, which he regarded as one of the grave evils of our present civilisation. Every great profession, he thought, needed "a deposit of faith" and that applied particularly to a profession which did not know exactly what its raw material, electricity, was. Kelvin's doctrine that a thing could best be understood when it could be expressed in terms of numbers was not enough. Engineers also needed to apply John Hopkinson's test—"whether the thing looks just about right." Sir John Hacking, the president of the Institution of Electrical Engineers, who responded to the toast, spoke of education as one of the major interests of the Institution. Referring to the growing demands for trained engineers, he said that there were indications that the electrical industry was not getting enough entrants. The need for rapid improvement would be met not so much by setting up new kinds of educational establishments as by enhancing existing facilities and making better use of them. The toast, "Our Guests" was proposed by Mr. J. R. Beard, past-president of the Institution. Field-Marshal Sir William J. Slim, Chief of the Imperial General Staff, who responded, referred to the shortage, in the Fighting Services, of electronic equipment and of the engineers and technicians to maintain that equipment. There was, he said, an urgent need for qualified men from industry to serve in the Territorial Army and the other auxiliary forces.

Founders' Company Fellowships

THE Worshipful Company of Founders of the City of London has this week circulated some particulars of the Fellowships which it awards to give facilities for advanced education to men who have already completed their normal course of training. The Company believes that the development and progress of founding and the science of metallurgy depend very largely on attracting to the industry highly trained men of evident talent. Candidates for the Fellowships must have been trained at a university or must be "at least of a high educational standard." Fellows are chosen by a selection committee from among applicants who have completed training in chemistry, physics, metallurgy (more especially in connection with molten metal), and allied sciences. In addition, previous practical foundry training and experience, together with, if possible, the diploma of the British Foundry School, will carry weight with the selection committee. But the committee pays considerable attention to the candidate's character and powers of initiative. The course to be followed by a Fellow is in each case chosen with the object of adding to his scientific equipment that which appears most necessary for adapting him to some branch of the founding industry. There is no limitation to the nature of the course which may be selected; it may include research, a period in works, or foreign experience. The normal value of a Fellowship is £300 a year, and it is renewable for a second year and, in special cases, for a third year. Candidates must be not less than twenty-one years of age on September 1st of the year of application. Applications must be received not later than May 1st by the Clerk of the Worshipful Company of Founders, 13, St. Swithin's Lane, London, E.C.4, who will furnish particulars of the Fellowships.

Fuel Research

A REPORT entitled *Fuel Research, 1949 to 1950*, was published by H.M. Stationery Office at the end of last week. It reviews the work of the Fuel Research Board of the Department of Scientific and Industrial Research between April, 1949, and December 31, 1950. The last report of the Board dealt with the period 1946–49, and was concerned mainly with the transition from short-term wartime researches to post-war reconstruction projects. The present report says that, during the twenty-one months reviewed, some increase in the accommodation and facilities at the Fuel Research Station at Greenwich was effected by the erection of temporary laboratories, though the difficulties of recruiting staff and obtaining equipment continued. The Board's main effort has been concentrated on the more efficient use of fuel, and the report notes that investigations to that end have yielded results which are being applied successfully in industry. Work on the elimination of smoke from hand-fired boilers has been extended to show that the reduction in smoke is accompanied by an increase of efficiency of up to 10 per cent. A comment made in the report is that since at least 20,000,000 tons of coal are burnt annually in Great Britain, a saving of 5 to 10 per cent would be a valuable contribution to the country's fuel economy. The report also notes that work on the testing of stoves and grates designed for burning solid fuel with higher efficiency has been continued both at the Fuel Research Station and at the Scottish branch station at Thorntonhall, near Glasgow. Other work referred to in the report includes an investigation into the possibilities of producing satisfactory metallurgical coke by carbonising blends of first-grade coking coal with other more plentiful coals. Large-scale experiments are being conducted by the Fuel Research Station, in collaboration with the National Coal Board. In addition, experiments have been continued on the gasification of fine low-grade coals and cokes in order to provide producer gas, water gas, and gas for the synthesis of oil. An investigation is proceeding on the combustion of coal to provide energy for the gas turbine, and methods are also being studied for the removal of sulphur compounds from flue gases, particularly in relation to the gases emitted from electricity generating stations.

Chamber of Shipping Annual Report

LAST week the Chamber of Shipping of the United Kingdom, which celebrates the seventy-fifth anniversary of its formation this year, issued its annual report for 1951–52. The main factors affecting shipping, the report states, have been the continuance of the Korean war, the rearmament programme and its demand for raw materials, Egypt's abrogation of the 1936 treaty and the subsequent dislocation of the Suez Canal traffic, and the nationalisation of the oil industry in Persia which has affected oil supplies over a wide area. Vigilance has had to be maintained with regard to the growing German and Japanese competition, the spread of flag discrimination and the problem of delay of ships in port. Referring to the full order books of British shipyards the report notes that more than half the total tonnage is on tanker account and without the pressing demand for this class of vessel the picture would be very different. The age distribution of tonnage is considered and the report states that the fleet includes a large number of wartime-built ships which have a short economic life so that replacement will eventually prove a serious problem. This is coupled with rising costs and heavy taxation, and the latter, the report recalls, was the subject of a memorandum submitted to the Government last year in which the danger of discontinuing the initial allowance was stressed. Another matter dealt with in the report is the need to maintain competitive equilibrium between coastwise shipping and internal transport.

Collaboration in Gas Research

A STATEMENT issued jointly by the Gas Council and the Society of British Gas Industries announces that as a result of discussions between the two bodies a joint consultative committee on research is being formed. It is pointed out that this plan for collaboration, whilst paying due regard to the fact that the problem of securing co-ordination within the gas supply industry has virtually been solved by nationalisation, recognises that the S.B.G.I. remains an association of firms in competition with one another. The plan evolved embraces, first, research work reserved respectively to the Gas Council and to individual member firms of the S.B.G.I.; secondly, research undertaken by mutual arrangement between the Gas Council or the area boards, and one or more individual firms, and, thirdly, research offering scope for collaboration between the Gas Council and the S.B.G.I. on a group basis. Under the first and second headings, there will be, in effect, a continuance of what has been the practice for many years, although the wider resources of the Gas Council and the area boards should offer a larger field of opportunity for both the supply industry itself and for individual firms working in collaboration with it. To give effect to the direct collaboration between the two bodies under the third part of the plan, a Joint Consultative Committee on Research will be formed with equal numbers of members from each body.

Leonardo da Vinci Exhibition

THE Diploma Gallery of the Royal Academy, Burlington House, London, which has been closed since 1939, was reopened yesterday, March 6th, with an exhibition commemorating the 500th centenary of the birth of Leonardo da Vinci. The exhibition includes a selection of more than 250 original drawings from the Royal Collection at Windsor, the British Museum, the Ashmolean Museum, Christ Church (Oxford), and other sources. Leonardo da Vinci's work as a scientist is illustrated in a separate section of the exhibition, which has been prepared by the Science Museum. This contains thirteen models of mechanical and other devices—specially constructed to da Vinci's original designs—and drawings and manuscripts, including the Codex dealing with water which has been lent by the Earl of Leicester. This part of the exhibition also includes reproductions of similar material in foreign collections. The contemporary copy of "The Last Supper," attributed to Marco D'Oggiono, which was purchased by the Royal Academy in 1821, is also exhibited, together with a number of versions of lost original paintings by Leonardo da Vinci, and other works by his immediate followers.

CROSS-CHANNEL STEAMER "NORMANNIA"

First-Class Smoke-Room and Bar

Third-Class Gentlemen's Lounge and Sleeping Berths

The Restaurant

First-Class Deck Lounge

Cross-Channel Steamer "Normannia"

By G. W. TRIPP, O.B.E., F.C.G.I., M.I.C.E.

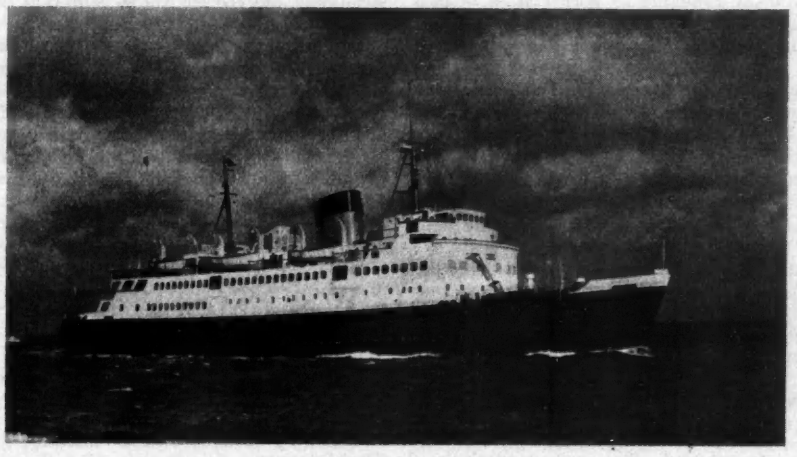
No. I

The cross-channel steamer "Normannia" entered the Southampton/Havre service of the British Railways on March 3rd, replacing the original "Normannia," lost at Dunkirk in May, 1940. The ship has a length between perpendiculars of 291ft, by 48ft breadth moulded, by 25ft 6in depth moulded to the upper deck, and a tonnage of 3543 gross. Two sets of double reduction geared turbines of 8000 total s.h.p. give the ship a speed of 19½ knots.

THE advent of a new "Normannia" revives the name of a notable cross-channel steamer. She and her sister ship, "Hantonia," were the first vessels of this class to be propelled by geared turbines and so successful was their performance that before long the principle was adopted for all cross-channel steamers. To the credit of the then South Eastern and Chatham Railway is the fact that the first cross-channel ship to be turbine driven, "The Queen," was put into service by that company, being built in 1903, to be followed by six sister ships, while the London, Brighton and South Coast Railway followed suit, and "Brighton" appeared in the Newhaven to Dieppe service later in 1903. It was not until 1910 that the third railway competing for the Continental traffic, the London and South Western, adopted the turbine principle and two triple screw steamers, "Caesarea" and "Sarnia," were built, primarily for service to the Channel Islands. So satisfied were their owners that they determined to place turbine steamers on the sailings between Southampton and Havre, with the result that in 1911 "Normannia" and her sister took up their station at Southampton. Perhaps the most noticeable characteristic of these ships was their smooth running—the vibration astern, one of the drawbacks of the triple screws connected direct to the high-speed turbines, being reduced to a minimum.

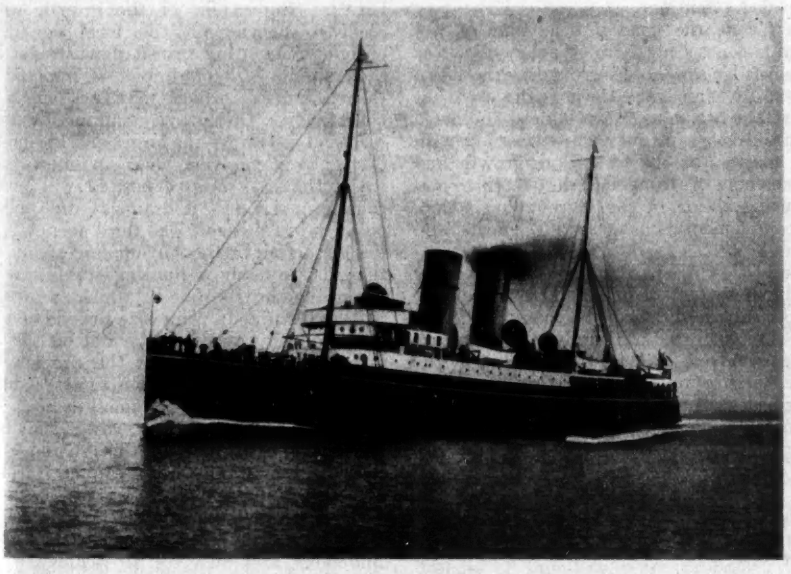
"Normannia" (illustrated herewith) was built by the Fairfield Shipbuilding and Engineering Company and had the following dimensions: length 290·3ft, breadth 36·1ft, depth 15·3ft, and a tonnage of 1509 gross. Her four steam turbines drove twin screws through single-reduction gearing and gave her a speed of 21 knots. Another distinctive feature was her cruiser stern, then a novelty in ships of this class, but one that soon gained favour. After less than three years' service the Great War broke out and she had to abandon her peace-time duties, but happily survived the war, and was able to resume her normal sailings. She was, however, not so fortunate in the second war, in which she became a military transport, and in common with many another good vessel, she came to an untimely end in May, 1940, off the Dunkirk beaches. "Hantonia" survived both wars, but after over forty years of service her days are numbered, for the new ship will be able to accommodate half as many passengers again as the two older ships combined.

The new "Normannia," the subject of this article, is to be engaged on the same duties as her namesake and entered on her regular sailings on March 3rd. She was launched last July at the yard of her builders, William Denny and Bros., Ltd., Dumbarton, and has the following dimensions: length overall 309ft, between perpendiculars 291ft, breadth moulded 48ft, depth moulded to upper deck 25ft 6in, tonnage 3543 gross. As will be seen from our illustration, she is a good-looking craft, with one large streamlined funnel, two tripod masts, raked stem and cruiser stern. To facilitate manœuvring when steaming stern first, she has been provided with a bow rudder. A large balanced main rudder, as well as the bow rudder, are both powered by twin motor electric hydraulic steering gears with telemotor control supplied by Brown Bros., and Co. Ltd. of Edinburgh.



THE "NORMANNIA" OF 1952

The general layout of the ship is as follows: there are two continuous decks, main and upper, with a promenade deck amidships above the upper deck, and over the forward end of the boat deck is the navigating bridge. The lower deck is forward and aft of the machinery spaces. Welding has been largely employed in the construction of bulkheads and for the butts of the shell plating. Subdivision is provided by ten water-tight bulkheads, the horizontal sliding water-tight doors being electrically operated and controlled from the wheelhouse. The wheelhouse has large windows at both front and sides and Kent clear-view screens are arranged in two windows facing forward. Behind the wheelhouse is a well arranged chart room. There is provided a full equipment of modern navigational instruments, comprising Marconi "Radiolocator" marine radar, a "Fathometer" echo sounder, a Chernikieff electric log recorder, Willet Bruce automatic whistle control, Siemens-Elliott engine revolution indicators, Siemens rudder indicators, Siemens electric main and emergency engine telegraphs and docking and steering telegraphs, and a 10in signalling projector. A Clifford and Snell loud-speaking telephone and amplifying system provides communication between bridge, engine-room and mooring positions. An Ardente sound reproduction unit facilitates communication between the bridge and the passenger and crew quarters. The steering telemotor for the



THE "NORMANNIA" OF 1911

main rudder is in the wheelhouse, while there is one for the bow rudder on each bridge wing. On the poop deck is secondary steering for the main rudder with hand gear. The wireless installation has been supplied by the Marconi Company and includes a main and emergency W.T. equipment with radio telephone facilities. Also installed are an auto-alarm and radio direction finding equipment.

The passenger accommodation, which we illustrate, is of a very high standard, and that provided for third-class passengers is above that found in the first-class of older ships, while comfort is evidenced also in the crew's quarters. On the promenade deck is a spacious and comfortable smoke room and bar with a good look-out all round, and there is also a first-class lounge and, further astern, a third-class lounge and smoke room. On the upper deck forward are three-berth cabins and amidships are two cabines de luxe, and also a small ladies' rest room. Abaft of this is a spacious and well-found restaurant available to both classes of passenger and seating 104 persons. On the main deck will be found accommodation for the crew, two-berth cabins, and two general sleeping lounges for third-class passengers. On the lower deck forward and aft of the engine and boiler-rooms, are two-berth cabins and five single-berth cabins. Sleeping berths throughout the vessel are fitted with Dunlopillo mattresses and there are, in all, berths for 325 persons. The "Normannia" has accommodation for 1400 passengers and carries a crew of seventy-one. The captain and navigating officers have their quarters on the bridge deck, the captain being given a day room, bedroom and bathroom. The engineer officers' cabins are at the after end of the boat deck and they have direct access to the engine-room. There is also a mess room, bathroom and office for them. Petty officers, seamen, &c., are catered for on the main deck, having their own mess rooms, wash-places and shower baths.

As a new departure, Pullman cars are to be introduced on the boat's expresses between London and Southampton in connection with the sailings of "Normannia."

In going over this vessel the first impression is that of spaciousness and comfort, while at sea the smooth running and lack of vibration is very marked; indeed, even at the very stern there is a remarkable steadiness, but the sea was so calm that there was no need to try the stabilisers. On going into the engine-room the orderly layout was very noticeable, but what seemed the best quality of all was the pleasant temperature and the unusual quiet. Builders, owners and travellers should be well content with this latest addition to the fleet of the Southern Region of British Railways.

(To be continued)

The Flow of Wet Steam

By DENIS J. RYLEY, M.Sc. (Eng.) (Lond.), A.M.I.Mech.E.

No. I

The flow of steam through nozzles has been the subject of much research. But almost the whole of the work has been conducted using steam which has remained superheated. The position relating to the flow of wet steam is different. Here the author sums up briefly the extent of present knowledge. A number of facts are also drawn from the author's own researches on a nozzle-testing apparatus described in a former issue of this journal.

THE flow of steam, particularly through nozzles, has been the subject of an immense amount of research extending over a period of about sixty years. This research has been promoted by the necessity of understanding the laws which govern the energy conversion taking place in the nozzle, as the efficiency of a steam turbine is directly related to them. A very great deal of knowledge, much of it experimental and descriptive, has now been amassed. If the relevant experiments be reviewed, it will be found that almost the whole of the work, directly relating to nozzle characteristics as such, has been conducted using steam which has remained superheated. Nor is this surprising, since steam most nearly conforms to the perfect gas laws when the state is far removed from conditions of saturation. There has also existed, since 1839, the mass flow equation for perfect gases, usually associated with the names of de St. Venant and Wantzel, which gives close correspondence between theory and practice for all superheated compressible fluids. The possession of this equation, together with an increasingly accurate knowledge of the properties of steam has encouraged a continuous and fruitful cross-fertilisation between theory and practice.

The position concerning the flow of wet steam, however, is very different. The behaviour of wet steam, both dynamic and thermodynamic, has long been known to be capricious and unpredictable and experimenters have avoided wet steam wherever possible. There is nothing blameworthy in this attitude, as the whole subject presents well-recognised difficulties and there is no merit in incurring additional unnecessary ones. At two points, however, steam engineers have been obliged to take cognisance of the behaviour of wet steam because the respective phenomena of supersaturation in nozzles and erosion of l.p. turbine blades have compelled attention.

As far as the general behaviour of wet steam is concerned, therefore, the only areas of knowledge are those surrounding these two effects. It is recognised in a vague way that wet steam has a large and almost unknown natural history of its own concerned with such matters as the formation, growth and movements of droplets, the tearing and atomising action of the surrounding steam, the complementary heat transfer effects, and so on.

The following paragraphs sum up very briefly the extent of present knowledge as it exists dispersed through many different published papers. A number of facts are also drawn from researches conducted by the present writer[1] on a nozzle testing apparatus[2] described at length in a former issue of this journal.

The Formation Size of Water Droplets

There appear to be three sets of circumstances wherein condensation of steam may occur:—

(*a*) It may occur "normally" upon the withdrawal of heat from saturated or wet steam. Under these conditions the process is thermodynamically reversible, and there is at no point any thermal disequilibrium. This case is very nearly—but never quite—realised in condensers.

(*b*) It may occur when completely supersaturated steam reaches the limiting degree of supersaturation, i.e., when its static state point crosses the so-called Wilson line on an entropy chart. The ensuing condensation is irreversible. The position of the Wilson line is only known with relative certainty in the low-pressure region and even here there is some disagreement between different experimenters (Yellot[3], Rettaliata[4], Binnie and Woods[5]).

(*c*) Condensation may co-exist with supersaturation. This corresponds to a state of partial supersaturation, or, as Mellanby and Kerr[6] have designated it, "fractional reversion." Fractional reversion will occur whenever expansion in the normally wet region is slow or interrupted. The writer has recently conducted nozzle experiments[1] using wet steam originally in equilibrium. The expansion rates were very slow and the supply of nuclei excessive. Some degree of supersaturation was found to occur with almost every type of nozzle. It would seem that this must be regarded as the normal occurrence with (*a*) and (*b*) above, as the respective limiting conditions in either direction.

It is not known whether the formation size of droplets is the same for all the above cases. As regards (*b*), there is a convergence of opinion (Yellot[3], Callendar[7], Martin[8], Powell[9], Binnie and Woods[6]) that the diameter lies in the range 10^{-8} to 10^{-9} feet. There are two methods of determining drop size. The theoretical method is by use of the well-known Kelvin-Helmholtz equation. The experimental method makes use of an arc lamp to generate an intense light which may be scattered by the droplets. By observation of the colour of the haze obtained the magnitude of the droplets may be assessed within fairly narrow limits.

Jeans[10] quotes $1{\cdot}5 \times 10^{-9}$ feet as the molecular diameter of water vapour, this result being a deduction from viscosity experiments. It would seem, therefore, that the smallest drops consist of a few molecules only of water.

Formation drops are generally found to grow rapidly in size. Visual confirmation of this fact is given by a change in the colour of the haze in arc lamp experiments (Yellot[3], Rettaliata[4]). The extent of the growth would seem to depend on the local conditions encountered during transit downstream and a maximum size of droplet is imposed by three agencies, which may act singly or collectively. Thus gravity and inertia effects will tend to remove the larger and less mobile drops by deposition, and in most cases water that has been deposited will not be re-entrained unless it drains to and collects on an exposed edge. The third agency is the tearing action of the surrounding steam and there is probably a limiting stable size for given conditions above which a droplet will be disrupted. This size depends on the steam density and velocity and on the surface tension and shape of the droplet, and no quantitative information exists concerning the terminal sizes for small drops. With regard to larger drops, whose diameters lie in the range 0·02–0·16in, Upton[11] has made a useful preliminary inquiry from a theoretical standpoint by analogy with the tearing of raindrops in the atmosphere.

An occasional drop defies the above influences and survives to achieve a size considerably in excess of the statistical terminal value.

It is now necessary to consider what takes place if there are any inequalities in temperature at any point within wet steam. Such inequalities may arise from the addition or withdrawal of heat at the boundary, or from differences in temperature between droplets and surrounding dry steam. Heat transfer through the vapour only involves the usual agencies of conduction and convection, with radiation playing a minor part. As regards the droplets, the small size probably limits the heat transfer to that due to conduction only. The transfer of heat across the interfaces between steam and droplets involves problems only partially understood. Theory suggests and experiment confirms that heat is transferred with extreme rapidity to or from drops of approximately formation size but takes longer with larger drops, especially if the temperature difference is less than about 2 deg. Fah.

No drop can in theory exist indefinitely in an atmosphere wherein the vapour pressure is the standard value for the prevailing temperature, as the standard value is defined with reference to a meniscus having an infinite radius of curvature. Such a drop will tend to evaporate and the tendency will be more pronounced the smaller the drop. The readiness of small drops to re-evaporate has been demonstrated by means of the arc lamp method described above (Rettaliata). Thus when wet steam suffers recompression in a convergent-divergent nozzle operating with an excessive back pressure, the droplets re-evaporate immediately saturation conditions are reached.

The subsequent behaviour of droplets precipitated by condensation during the expansion of wet steam has received no attention. Thus a given drop finds itself in a rapidly cooling atmosphere with a rapidly declining pressure. If it is very small it may keep step in temperature, losing its heat across the meniscus to the immediate surroundings. Alternatively and perhaps concurrently, it may give rise to "flash" steam at the surface. In extreme circumstances a large drop (say, 10^{-2}ft diameter), whose relative structural strength is low, may explode due to ebullition within the hot core, aided by tearing at the surface. No criteria are available for deciding what will happen in a given case.

Orthodox theories lose sight of the water content in expanding wet steam and make the tacit assumption that thermal equilibrium obtains at the end point of the expansion. It is probable in the case of a nozzle, owing to the extremely small time of transit that hot droplets are discharged and that the actual heat drop is slightly less than the nominal effective heat drop. An estimate of the approximate loss can be made for a specific case as follows. Consider the expansion from 100 lb per square inch absolute to 10 lb per square inch absolute of 1 lb of steam originally dry saturated. The precipitation may be divided into, say, four batches of droplets. On the assumption that the droplets of each batch cool through half the required temperature range, it may be shown that the defect in heat drop amounts to about 4·2 B.Th.U. Comparing this with the nominal adiabatic heat drop of 164 B.1h.U., it represents a loss of some 2½ per cent. The actual loss is probably less than this.

For the purpose of elementary calculations on the flow of wet steam it is usually assumed that the water droplets have the same local velocity as the dry steam in which they are entrained. This is only true in the exceptional case. In general the droplet velocity will differ from that of the steam and will usually be less. Since, at a given cross section perpendicular to the flow, droplets of all sizes up to the maximum may be present, there will be a wide range of droplet velocity. It may be assumed, as a first approximation, that there is a "mean effective velocity," V_w, constant for all drops and such as to promote the same mass flow of drops as is actually taking place. The ratio of this velocity to that of the dry steam at this section, V_s, may be termed the "drift velocity ratio," f, such that $f=V_w/V_s$.

Mathematical manipulation is further facilitated by considering that the dry steam and the water flow in separate streams, each having its own distinct velocity. This is tantamount to considering that a small part of the flow area is engaged in passing a thin water filament only, whilst the remainder is engaged in passing the dry steam content at a greater velocity. This idea is developed at greater length hereafter.

Dryness Fraction

It has been customary to define dryness fraction rather loosely as the weight of dry steam per unit weight of mixture. This definition makes no reference to the manner of the association between the water and dry steam contents, and hence the term "apparent dryness fraction" has come into currency. This term is used somewhat indiscriminately for all cases where the manner of the association is imperfectly known. In order to accommodate the idea of the drift velocity ratio and to try to give greater precision to the definition when applied to flowing steam, the writer suggests three viewpoints as follows.

(1) If 1 lb of mixture, whether stationary or moving, contains at a given instant q_R lb of pure dry saturated steam disposed in any manner, the real dryness fraction is said to be q_R.

This definition is considered to be valid whatever movements the droplets may have at the instant under review. If, as is usual, the droplets have a disorderly motion and/or a non-uniform distribution, q_R will undergo continuous variation. This definition is substantially the existing definition for dryness fraction.

(2) If the steam in transit through a channel has entrained water droplets moving more slowly than the steam, a sampling pipe leading to a throttling calorimeter may fail to acquire a representative sample, but may pick up a reduced amount of water. The dryness fraction of the sample is thus rendered ficticiously high. If q_R is the real dryness fraction for the steam in the main, considered constant, and f is the drift velocity ratio applicable to the sampling pipe, it may readily be shown that the measured dryness fraction is given by $q_M=\dfrac{1}{f/q_R+(1-f)}$.

If this is true, the question of why it has escaped unnoticed so long is immediately provoked. The answer is found in the fact that the lowest value of q_R ever dealt with in a throttling calorimeter is 0·95, approximately, and for the higher values of f which almost certainly occur in practice, the error is sufficiently small to be overlooked. Thus, when $f=0·8$ and $q_R=0·95$, $q_M=0·96$. This disparity between q_M and q_R may account in part for the difficulty often experienced in obtaining agreement between experimental values of q_M obtained with different equipment for the same steam main. It has been customary to attribute the difficulty to the method of sampling and since different designs of sampling pipes probably confer differing values of f upon the sample, the diagnosis would seem to be correct.

(3) It is necessary to envisage a further dryness fraction which may be referred to as the chart dryness fraction and may be understood as follows. Suppose a given mass of steam has undergone a definite expansion between any two static states on an entropy (or other) chart. Suppose, further, that the end point is in the wet field and that no supersaturation exists at this point. During the expansion a certain amount of water will have been formed and the mixture must finally be such that the correct proportions of dry steam and droplets shall be discharged. These proportions are in the ratio $q:(1-q)$ where these quantities are as indicated by the chart.

To distinguish between q and q_R it is necessary to remember that a given amount of water may be considered as crossing a datum section as a fast-moving stream of small cross section or a slow moving stream of larger cross section. The real dryness fraction is small in the first case and larger in the second, but the chart dryness fraction is unchanged.

Using these definitions, together with the usual equations for mass continuity, it is possible to obtain equations relating any three of the four quantities, q_R, q_M, q and f.

The Energy Equations for Wet Steam

The total energy possessed by wet steam will be the sum of the separate total energies of the dry saturated content and of the droplets respectively. The former is obtained in the usual way by summing the internal and external energies together with any kinetic and/or potential energy. The same applies to the droplets, though a separate term to cover the energy concentrated in the surfaces is convenient in problems where large changes in aggregate surface area occur.

If an actual case be taken it may be shown that the energy concentrated in the droplets for most normal cases represents a very small proportion of the total. Thus, suppose a wet steam mixture has a pressure of 100 lb. per square inch absolute, and the steam velocity, V_S, is 1000ft per second, as appropriate to the outlet section of a convergent nozzle. Suppose, further, that $q_R=0·9$ and that f=unity. Then, considering 1 lb of mixture :

	B.Th.U.
Enthalpy of steam	1069·4
Kinetic energy of steam	18
Sensible heat of water	29·9
Kinetic energy of water	2

The energy contained in the drops is thus only some $^{32}/_{1120}=2·85$ per cent of the total. For any value of $f(0—1·0)$, and any dryness fraction likely to occur in practice, the kinetic energy of the droplets is almost negligible, and the total energy very small. For this reason, any attempt to find the value of f using a calorimeter or impulse device operated by the droplets themselves is likely to prove unprofitable.

By considering the steam and water to flow in separate streams as indicated above, a new approach may be made to the vexed question of the discharge coefficient for wet steam, and this topic will form the subject of a further article.

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(*To be continued*) 363

The Severn Bridge Investigations

Tests on the aerodynamic stability of the proposed Severn suspension bridge have been carried out at the National Physical Laboratory, and a report of the investigations has just been published. The purpose of the work was to give guidance in the design of the proposed bridge, but much of the information gained is applicable to suspension bridges generally.

THE aerodynamic behaviour of long-span suspension bridges is by now a well-known phenomenon, largely on account of the spectacular failure of the Tacoma Narrows bridge, U.S.A., in 1940. Since that date, the design of such bridges to resist the aerodynamic effects of strong winds, has been the subject of much research. The description which we give below is abstracted from the recently published final report* of the investigation carried out by the National Physical Laboratory for the design of the proposed Severn bridge.

The investigation was carried out on behalf of the Ministry of Transport during the years 1946 to 1951. The construction of a new roadway crossing of the River Severn estuary was proposed by means of a suspension bridge with a main span of 3000ft and anchor spans of 1100ft. Since several bridges of this kind had in varying degrees been subject to peculiar aerodynamic effects, resulting in some cases in complete failure of the bridge, the consulting engineers (Messrs. Freeman Fox and Partners and Messrs. Mott Hay and Anderson) had asked for an investigation of the problem, so that as satisfactory and economical a design as possible might be evolved.

It was laid down that the purpose of the research was "to ascertain reliable and economical forms of deck and stiffening truss structures and the effects of other features of the structure which may react on the tendency to oscillate." A number of design features were suggested as having a possible influence on the aerodynamic oscillations. They included the kind of stiffening truss, the separation of the roads by open gaps, the ratio of the bridge width to the span length, and the level of the deck with respect to the stiffening girders. Suggestions for tests of complete bridge models and also for tests on models representing only a short length of the suspended structure, were made. It was considered that if this latter method could be shown to be reliable it could be used to establish the superiority of one or two forms of suspended structure. When the best form of structure had been decided it would be necessary to make final model tests to confirm the aerodynamic stability and to obtain information on the static wind forces for use in the calculation of wind stresses.

The Deformation of Suspension Bridges.—The main types of deformation which the structure of a suspension bridge can take up under conditions of practical loading are vertical bending, lateral (or horizontal) bending, and torsion. With vertical bending the displacements which are of primary importance in relation to bridge oscillations are the vertical translations of the cross girders, and the tilting of the cross girders from their vertical planes. With lateral bending the corresponding translations are lateral, and the angular movements are about the vertical centre lines of the girders. In the case of torsion the cross girders turn around the neutral axis of the structure and also warp. By warp is meant the twisting of the cross-girder planes themselves, and it is characterised by equal, but opposite-handed, tilting of the pairs of cross-girder posts concerned.

Any vertical movements of the cross-girder posts that occur will be transmitted to the cable bands through the suspenders. This will cause the cable bands to displace also horizontally along the span, since the links of cable connecting them can extend only very slightly. The suspenders therefore become inclined. Suspender inclination arises also from the angular movements of the cross-girder posts when (as is normally the case) the suspension points are offset from the neutral plane of the suspended structure.

In the case of torsion the effects are rather complicated since the suspenders become inclined both laterally (i.e., in vertical planes normal to the span) and longitudinally (i.e., in vertical planes parallel to the span). The lateral inclinations are due to the turning of the cross-girder planes about the neutral axis, and they introduce forces tending to disturb the cables from their vertical planes and also to bend the suspended structure laterally. The longitudinal inclinations are due partly to the cable behaviour and partly to the warp of the cross girders, and are opposite handed for the two posts of any cross girder. The two corresponding inclined suspenders then pull the cross girder posts spanwise in opposite senses and so contribute a movement tending to bend the structure laterally. It is seen, then, that with torsional loading, lateral bending can be induced in two ways. Lateral forces can result from the twisting of the structure, and lateral bending movements from the cross-girder warp and from the cable geometry.

When a bridge is oscillating the live loading arises effectively from inertia. With torsional oscillations some lateral movements can be induced by the effects just referred to and also by any offset of the centre of mass of the suspended structure from the horizontal neutral plane. This inertia coupling will evidently be most pronounced for bridges possessing a single road deck placed either at the top or at the bottom of the structure. With natural torsional oscillations the presence of a lateral component of motion will offset the effective centres of rotation of the cross girders to positions above or below the neutral axis which will vary along the span. A knowledge of these effects is important in relation to the production of torsional aerodynamic oscillations from wind tunnel tests of the pitching oscillation of sectional models. To provide the most complete information the range of practical positions for the centre of rotation should be covered by such tests. In the experimental investigations to be described allowances for a variation of the axis position were made, but the position was in all cases assumed to fall within the depth of the stiffening truss. Some justification for this limitation was provided by observations of the torsional oscillations of a full model of a mid-deck form of bridge. In this case the twisting at all cross girders was very closely about the roadway centre line. More precise information on the coupling effects between torsion and lateral flexure is certainly desirable, but unfortunately it is beyond the scope of any existing theory. Illustrations of the effects are seen in the Tacoma Narrows bridge film. Some of the very large torsional oscillations which preceded the first collapse of the bridge show appreciable lateral movements of the cables and deck platform.

Natural Oscillations of Suspension Bridges.—Before aerodynamic oscillations are considered it will be necessary to understand how a suspension bridge would respond to a casual disturbance if all the damping forces due to the structure and to the surrounding air were removed. Under these idealised conditions the free oscillations following a quite general disturbance would appear very complex and irregular. They would, of course, persist for an indefinitely long time. However, with special simple disturbances the oscillations would be of the simple harmonic type, and all points of the bridge would move regularly and in step. With any given bridge design there are numerous possible varieties of these so-called natural oscillations, and they have different frequencies and different modes of displacement according to the special simple (natural) disturbance. A general disturbance is mathematically equivalent to a combination of the natural disturbances taken in suitable proportions. Hence, also, the most general free oscillation, though apparently very irregular, is only some superposition of the regular natural constituents. These ideas are, of course, basic in oscillation analysis generally.

Since a suspension bridge has constructional symmetry about the vertical plane through its spanwise centre line, the natural oscillations can be of two types. With the one type the movements on the opposite sides of that plane are equal and in the same phase, and the deformation occurring is vertical bending. With the other type the movements are equal, but oppositely phased, and are characterised by torsion and lateral bending. In this case the torsion or the lateral bending will predominate according to the frequency.

A further classification depends on the fact that the bridge also has constructional symmetry about the vertical plane which bisects the span at right-angles. The two halves of the total span can therefore move equally, either in the same phase or in opposite phases. In the first case, the oscillations are said to be symmetric, and in the second case anti-symmetric. With symmetric oscillations movements must take place at mid-span, so the total number of nodes contained in the span is even; with anti-symmetric oscillations a node is present at mid-span, and the total number of nodes in the span is odd.

Vertical bending oscillations and torsional oscillations will be accompanied by substantial vertical movements of the cable and, in some cases, by movements of the towers and side spans. With symmetric oscillations of these types the cables displace only vertically at mid-span, but can have marked horizontal movements at the towers. With anti-symmetric oscillations, the horizontal movements of the cables can be marked at mid-span, but will in general be small at the towers.

Aerodynamic Oscillations of Suspension Bridges.—The normal action of wind on a suspension bridge is to displace the structure to a new equilibrium position. Gusts and their occasional impulses will cause disturbances which are followed by small free oscillations of the bridge, but, with a stable design, any movements of this sort die away, and the equilibrium position is continuously resumed without significant departures. The action of the load is therefore effectively static. With an unstable design, however, free oscillations increase for some wind conditions and may become serious.

When a bridge is in still air its free oscillations die away owing to the positive damping due to the structure and the air. These damping forces are small in relation to the enormous inertia and their main effect is to cause the natural constituent oscillations to become damped to various different extents without sensible changes of the natural modes and natural frequencies.

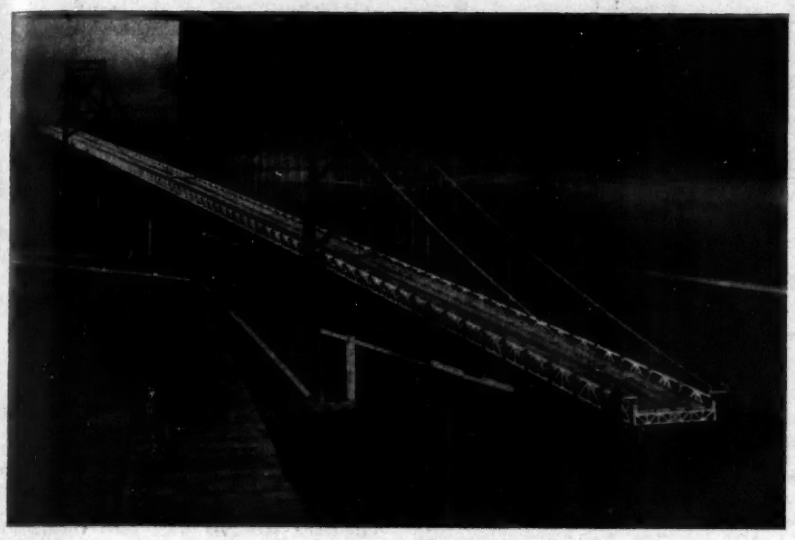
The experimental evidence is that when a bridge is exposed to a wind the effects are very similar, except in one very important respect. With certain bridge designs it is possible for the net damping (aerodynamic plus structural) of a constituent oscillation to become negative for certain wind directions and for certain ranges of the wind speed. At the end points of any such speed range the net damping is zero, so the oscillations occurring are simple harmonic. Any wind speed producing this condition is termed a critical speed. When the net damping is negative, the oscillations are unstable and therefore increase initially. Ultimately, the movements will either become maintained steadily at a constant finite amplitude, and so cause inconvenience to traffic, or they will continue to grow until a structural failure occurs. The issue here will depend on the severity of the negative damping and on the

* "A Summarised Account of the Severn Bridge Aerodynamic Investigation," by R. A. Frazer, D.Sc., F.R.S., and C. Scruton, B.Sc., A.F.R.Ae.S. Report No. N.P.L./Aero/222.

departures from linear relationships between loads and displacements.

It is possible for two or more constituent oscillations to become unstable simultaneously for a given wind condition. In this case one of the constituents so affected may overpower all the others. Alternatively, an irregular looking motion will develop due to the interferences between the different modes and different frequencies.

The critical wind speeds for which simple harmonic oscillations occur will be influenced by the external shape of the bridge structure, the frictional damping, and the wind direction. The experimental evidence is that with a given bridge and a given wind direction all the different vertical bending oscillations will be critically affected for roughly the same sets of values of the ratio $V_r = V/NB$, where V denotes the wind speed, N denotes the actual oscillation frequency at that speed, and B is the bridge width. This non-dimensional parameter is termed the reduced velocity. It is also found that with winds encountered in practice the influence of the speed on the frequency is small, so that as an approximation N may be replaced by the appropriate natural frequency in the evaluation of the reduced velocity. Torsional oscillations have similar properties. The liability of a bridge to unstable oscillations in wind can therefore be predicted once the critical value of the reduced velocities and the natural frequencies are known. The primary purpose of tests of model bridges in wind tunnels is the determination of the values of the reduced velocity.



"FULL" MODEL OF BRIDGE IN THURLEIGH WIND TUNNEL

With some bridge designs aerodynamic oscillations of a more complex kind, involving coupling between torsional and vertical bending movements in pairs, are also possible. Experiments carried out in this connection indicate that such oscillations are avoided if the corresponding pairs of natural frequencies are not close to equality.

A simple physical picture of the way in which wind action excites unstable oscillations of suspension bridges cannot be offered. The study of this intricate problem involves fundamental researches which were not considered to be within the scope of the Severn Bridge investigation. However, a few explanatory remarks on the aerodynamic forces concerned may be helpful. The bridge components which have most influence on the damping due to wind are the deck and the stiffening girders. If small steady oscillations having a given natural mode and the corresponding natural frequency were imposed on the system, vortex sheets and perhaps large-scale eddies would be generated periodically and carried downstream. The aerodynamic restoring force induced at any instant by the travelling vortex distribution would clearly not in general be in the same phase as the displacement of the system. It would, in fact, have a positive or a negative damping tendency according as it acted in advance of or lagged behind the displacement. These considerations are sufficient to account for unstable oscillations, although they do not help to explain why some systems are immune from instability while others are not. The difficulty is not peculiar to bridge sections. Torsional oscillations of aeroplane wings are stable when the mean angle of incidence is small, but can be unstable when the wings are stalled. The reasons for this behaviour have not yet been clarified theoretically. Bridge sections, and particularly truss-stiffened sections, are much more complex than wing surfaces, and no reliance could be placed on a purely theoretical determination of their stability characteristics. For this reason the investigation of the oscillations of suspension bridges must, at the present state of knowledge, depend very largely on experimental or semi-empirical methods. In the last decade the subject has been studied particularly from this point of view in the U.S.A. The aim in some of the investigations has been to throw further light on the ways in which unstable oscillations are excited; in others, it has been to provide simple notes to aid design against aerodynamic instability. In all this work much use has been made of wind tunnels to provide the necessary basic information.

Elastic Stiffnesses and Natural Oscillations.—Although the structural form of a suspension bridge is the most potent factor influencing the aerodynamic oscillations, the stiffnesses and natural frequencies play an important part in the design. The stiffnesses control the displacements when the bridge is loaded statically by traffic or wind. The natural frequencies influence the critical wind speeds at which unstable oscillations are introduced. From the remarks above in connection with the reduced velocity it will be seen that the onset of such oscillations occurs approximately at wind speeds which are directly proportional to the natural frequencies. Reliable determinations of the stiffnesses and frequencies are therefore important both for normal static structural design and for the prediction of aerodynamic instability. They are also a necessary aid in the design of model bridge structures.

In connection with the Severn Bridge investigation a special method was developed for the calculation of the stiffnesses and natural oscillations. The method is in certain respects analogous to one developed in the U.S.A. which has yielded natural frequencies and oscillation modes correlating well with those observed for models and full-scale bridges. However, the alternative treatment now proposed in the report is rather more complete in that it takes into account the discrete panelling of the bridge and the framing of the structure. Normally, in deflection theory, the span is assumed to be long, the suspended structure is regarded as a uniform beam, and the suspender loading is taken to be continuous over the span. A discrete treatment offers the advantages that it is applicable for any length of span and that it provides a clearer insight into the torsional properties of the bridge.

In common with all other existing forms of deflection theory, the method suffers from certain limitations. Perhaps the most serious limitation is the neglect of the inclination of the suspenders. Hence, no information is provided on the effects of coupling between torsion and lateral flexure.

Natural Winds and Artificial Wind Streams.—In the study of wind action on a suspension bridge, information of a statistical nature on the winds to be expected on the site is very desirable. An effort to obtain such information is being made by the joint engineers for the Severn Bridge with the use of special anemometers which have been developed by the Meteorological Office. The instruments are designed to record automatically the wind speeds and the horizontal and vertical inclinations at several positions simultaneously.

For the purpose of wind tunnel tests on bridge models it is usual to suppose that the wind is steady and distributed evenly along the span, and to place reasonable limitations on the wind speeds and wind directions. In the case of the Severn Bridge investigation it was assumed that winds of up to 100 miles per hour could be incident from any quarter and with a vertical inclination ranging between ± 15 deg. Only in a few special tests was any attempt made to simulate gusty winds.

It is, of course, extremely unlikely that a natural wind would ever be maintained evenly and steadily across the entire span of a long bridge, except perhaps for short periods. However, since the stability of a bridge section is influenced by both wind speed and wind direction, the most unstable condition for the complete bridge may be assumed to be when it is exposed to the most unfavourable combination of wind speed and wind direction at all positions along the span. In this respect, then, tests of model bridges in wind tunnels should give results erring on the safe side.

MODEL INVESTIGATIONS

Two methods of testing were utilised for the wind tunnel work carried out for the proposed Severn Bridge, involving the use of sectional models and a full-length model.

Sectional Models.—A sectional model is a rigid scale copy of a sample length of the suspended structure. Such a model can be used either to determine the stability properties of the section concerned for "rigid body" modes of oscillation, or for measurements of the static forces on the bridge structure due to wind. In the first case, the model is mounted across the wind tunnel with its span horizontal and normal to the wind stream, and allowed freedom to oscillate in simple ways against spring constraints. In most of the tests relating to the Severn Bridge, the freedoms permitted were pitching and vertical translation, which are the two-dimensional equivalents of twisting and vertical bending on the actual bridge. These movements were allowed to occur simultaneously in the study of coupled oscillations, or could be included for tests with a single freedom. A few experiments were also made with lateral translation included, corresponding to the lateral bending of the bridge.

Experiments with section models for oscillatory conditions are barely practicable in winds not directed normally to the span. However, with some complication of the model, measurements of static forces on such models are possible for any direction of the wind.

Tests of sectional models can be carried out in normal wind tunnels and without unduly elaborate equipment. As the models are rigid, minor modifications to them can be made, and the effects of systematic changes can be studied rapidly. In the Severn Bridge research the

stability tests usually involved no more than the observation and measurement of the critical wind speeds and frequencies bounding the ranges over which oscillations were maintained in wind. In some cases the damping rates of oscillations in wind were also measured.

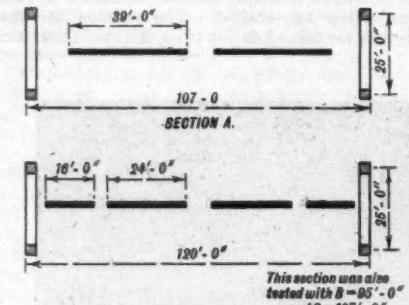
Full Models.—A full model is a replica of a complete bridge so constructed that it oscillates similarly to its parent bridge. Constructional conditions must be satisfied which ensure dynamic similarity.

The full model used in the course of the investigation, which is illustrated herewith, was over 50ft long. It required the construction of a special large wind tunnel, which was installed in a disused aircraft hangar at Thurleigh Airfield, in Bedfordshire, by the Ministry of Transport. The direction of the wind stream in the tunnel could not be varied, but horizontally and vertically inclined winds were effectively simulated by appropriate inclinations of the model itself. Critical wind speeds, frequencies and oscillation modes were recorded.

The Test Programme.—In the early stages of the investigation it was uncertain whether the stability of a complete bridge could be predicted satisfactorily from experiments on a sectional model alone, since with this method of test the influence of several factors cannot be represented directly. Such factors include, for example, the tower stiffnesses and inertias, the longitudinal camber, the mode of oscillation and the horizontal inclination of the wind. However, it was also clear that full models were unsuitable for routine comparisons between different forms of suspended platform, owing to the length of time required for construction and the high cost. To provide a practical programme it was therefore decided to depend on tests of sectional models to a linear scale of 1/100 for an indication of the most promising structural forms.

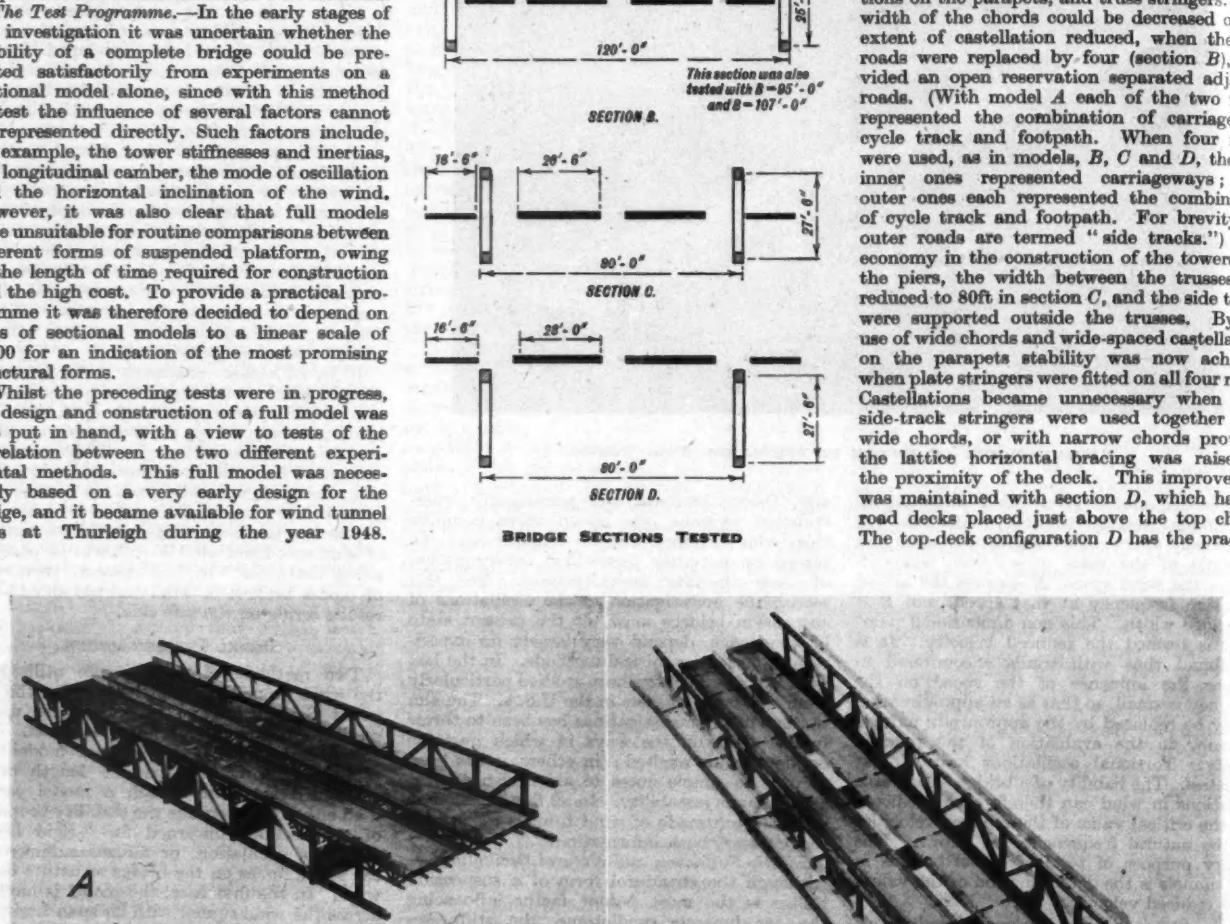
Whilst the preceding tests were in progress, the design and construction of a full model was also put in hand, with a view to tests of the correlation between the two different experimental methods. This full model was necessarily based on a very early design for the bridge, and it became available for wind tunnel tests at Thurleigh during the year 1948.

The results obtained with the two types of models led to the conclusion that tests of sectional models were sufficient for reliable full-scale prediction, and accordingly the construction of a further full model, based on the design finally preferred for the bridge, was considered to be unnecessary. To prove a final verification of the stability of this design, tests were carried out on a sectional model of linear scale 1/32. The increase of linear scale was considered to be advisable, because previous tests had shown that the stability was sensitively influenced by details of the structural form which could not be reproduced with sufficient accuracy to the scale of 1/100. The measurements of the static aerodynamic loads for the finally preferred design, were also obtained with a sectional model of linear scale 1/32.



BRIDGE SECTIONS TESTED

The sections *A* to *D* shown in the illustrations on this page, are lettered in the chronological order of test and illustrate successive stages in the evolution of a design with very good stability characteristics. A comparison between the different sections is difficult because certain small structural details influencing the stability were not common to all of them. When some advantageous features were included, stability was achieved with all the sections, but the number of stabilising features which had to be incorporated decreased progressively through the series tested. Section *A* required wide stiffening truss chords, close-spaced castellations on the parapets, and truss stringers. The width of the chords could be decreased or the extent of castellation reduced, when the two roads were replaced by four (section *B*), provided an open reservation separated adjacent roads. (With model *A* each of the two roads represented the combination of carriageway, cycle track and footpath. When four roads were used, as in models, *B*, *C* and *D*, the two inner ones represented carriageways; the outer ones each represented the combination of cycle track and footpath. For brevity the outer roads are termed "side tracks.") For economy in the construction of the towers and the piers, the width between the trusses was reduced to 80ft in section *C*, and the side tracks were supported outside the trusses. By the use of wide chords and wide-spaced castellations on the parapets stability was now achieved when plate stringers were fitted on all four roads. Castellations became unnecessary when truss side-track stringers were used together with wide chords, or with narrow chords provided the lattice horizontal bracing was raised to the proximity of the deck. This improvement was maintained with section *D*, which had its road decks placed just above the top chords. The top-deck configuration *D* has the practical



1/100TH-SCALE "SECTIONAL" MODELS

advantage that it permits the use of two widely separated planes of horizontal bracing which form, with the stiffening trusses, a box structure of great torsional rigidity. The consequent increase in the natural frequencies for the torsional modes, as compared with those of a bridge with a single plane of bracing, has the twofold advantage of yielding proportionately higher critical speeds and of increasing the separation between the natural frequencies of corresponding modes in torsion and in vertical bending.

A cross section of the 1/32 scale model used to verify the results obtained with the smaller scale is illustrated herewith. The tests indicated that with such a design no sustained torsional oscillations would arise from the action of winds below a speed of at least 210 miles per hour.

Conclusions.—So far as concerns the Severn Bridge project, the principal conclusion to be drawn from the investigation is that a bridge built to the proposed design will be free from unstable aerodynamic oscillations. Conclusions relating to the aerodynamic stability of suspension bridges generally, based on the evidence obtained, are listed below :

(*a*) Bridges stiffened by plate girders are liable to both vertical bending oscillations and torsional oscillations. The continuous blocked area which they present bluff to the wind appears to render them more prone to instability than truss-stiffened bridges.

(*b*) Bridges with truss stiffening are immune from vertical bending oscillations, and their tendency to instability in torsional oscillations can be corrected by suitable design of the suspended structure. Design features which have a corrective influence are :

(i) Stiffening-truss chords of high width/depth ratio.

(ii) Separation of roads by open slots or gratings.

(iii) Deck stringers of truss, in preference to plate design.

(iv) Castellated parapets, or other parapets designed to break up the continuity of the flow pattern.

(v) Side tracks mounted outboard of the stiffening trusses.

(vi) Lateral bracing of the lattice type fitted near deck level.

(*c*) A suspension bridge shows greatest instability in transverse winds (i.e., in winds blowing at right-angles to the span). The stability characteristics improve progressively as the horizontal inclination of the wind to the transverse direction is increased.

(*d*) Unstable oscillations are unlikely to occur in steady longitudinal winds with any type of suspended structure. It is possible that irregular movements may be caused in longitudinal or nearly longitudinal winds by the buffeting action of the eddying wakes shed from the towers. For this reason the incorporation in the towers of portal members of great depth would be undesirable.

(*e*) It is possible for certain types of gusts to excite erratic vertical bending and lateral swaying movements. No evidence was obtained that torsional oscillations are promoted by gusts, or that any regular oscillations of large amplitude can be excited by periodic gusts synchronising with a natural frequency.

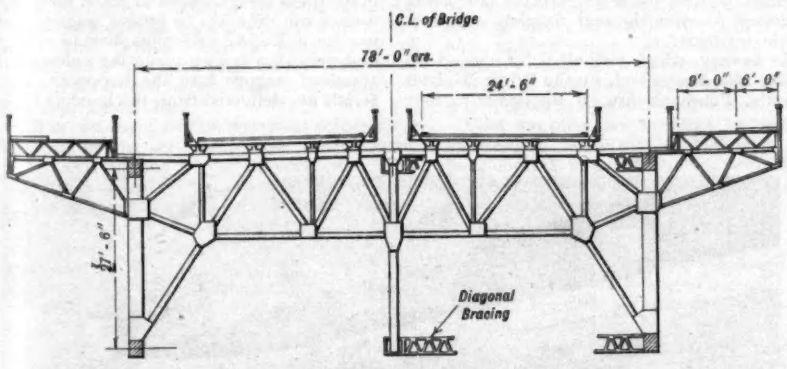
(*f*) The information listed under heading (*b*) can be used to help the initial choice of a design for a truss stiffened bridge. However, if any important new features are to be incorporated, confirmatory tests of the stability are advisable. For this purpose tests with sectional models are considered to be adequate.

(*g*) A sectional model should be sufficiently large to allow accurate reproduction of structural details, but aerodynamic interference effects from the roof and the floor of the wind tunnel must at the same time be avoided. Also, the model must be sufficiently long to avoid significant effects due to the changed pattern of the airflow near the ends.

(*h*) Oscillations involving coupling between corresponding modes of oscillation in vertical bending and in torsion are avoided unless the values of the natural frequencies concerned are close to equality.

(*i*) Further information on the structural damping properties of long-span bridges and on winds at bridge sites would be valuable.

(*j*) Further theoretical research on the natural oscillations of suspension bridges is desirable in order to clarify the effects of coupling between lateral flexure and torsion.



1/32 SCALE SECTIONAL MODEL

Sindri Fertiliser Factory

No. I

The fertiliser factory at Sindri, in India, which has now been officially opened, is designed to produce 350,000 tons of ammonium sulphate a year. It consists of four main sections : a power-house, a gas plant, an ammonium synthesis plant, and a sulphate plant. In its design and lay-out provision has been made to increase production in the future. The project is an example of co-operation between the Government of India and firms in this country and the United States.

IN 1943 the Government of India, prompted by the urgent need to grow more food for its increasing population, decided to embark upon a scheme to produce artificial fertilisers in large quantities, in order to help the farmers to obtain greater yields from their land. The Food Grains Policy Committee advised that, in the future, the country would require between two and three million tons of artificial fertiliser a year, and it recommended that as a first step immediate action should be taken to produce annually some 350,000 tons of nitrogenous fertilisers.

At the invitation of the Government of India a technical mission was sent out from this country in 1944 to examine and make recommendations upon the proposal to build a fertiliser factory of the required capacity. This mission was headed by Mr. G. S. Gowing, of Imperial Chemical Industries, Ltd., and consisted of Mr. J. G. Rigg, of the same organisation, and Mr. T. H. Riley, of the Power Gas Corporation, Ltd., representing the British Chemical Plant Manufacturers' Association. As a result of the mission's investigations and recommendations, an outline of which was given in our issue of March 4, 1949, it was decided to establish a factory of the required capacity at Sindri, on the bank of the Damodar River, in which water gas made from coke would be used to produce ammonia for conversion to sulphate by the gypsum or anhydrate process.

In 1945 the Government of India began to negotiate contracts for the scheme, and as the war was then in its closing stages, investigations were limited to this country and the United States. The conditions then prevailing made it desirable to use both British and American capacity for the project, and it was decided that there were sound reasons for adopting American designs. A contract was therefore placed with the Chemical Construction Corporation, of New York, for the design and engineering services of the plant. At the same time the Power Gas Corporation, Ltd., of Stockton-on-Tees, was entrusted with the organisation, procurement of plant and the co-ordination of erection.

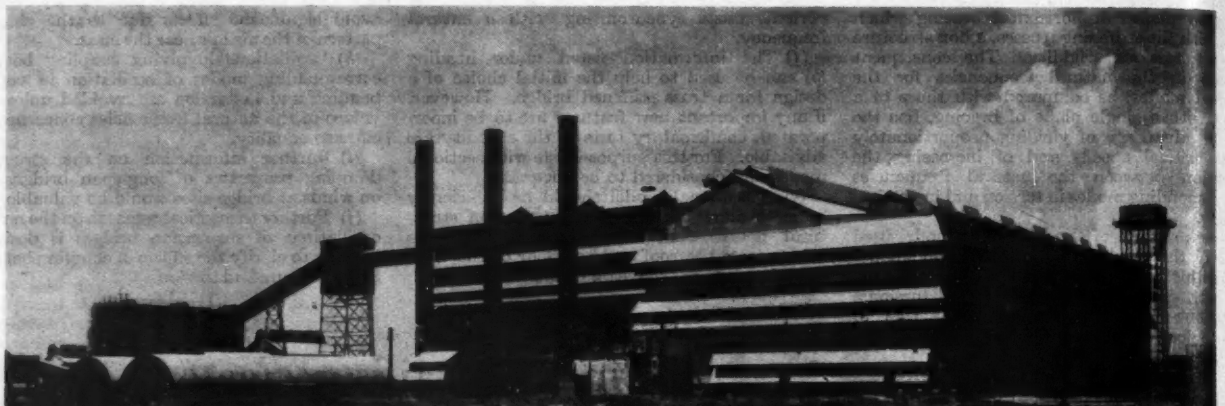
The size of the project and the uncertainty of world conditions at that time were such that no single firm would undertake the complete project and build a factory which would cost some £20 million. Consequently, under the final arrangement entered into, the Power Gas Corporation, Ltd., agreed to act as agents for the Government of India, purchase equipment to the designs of the engineers, and arrange for transport and procure services to erect the factory on the site at Sindri under the supervision and to the satisfaction of the Chemical Construction Corporation.

Under the official contract the Power Gas Corporation Ltd had to decide on the best firms for the particular work and issue inquiries for the supply, construction and erection of parts of the factory. In addition to checking all proposals and tenders received, it was responsible for the preparation and signing of all contracts with suppliers as agents of the Government. The company also had to investigate the ability of Indian contracting firms to supply, construct and erect parts of the factory ; to maintain contact with these suppliers to ensure expedition of the work ; and to inspect and pay for the work done. All transport was under the firm's control and it was responsible for co-ordination of manufacture and delivery to schedule as erection proceeded.

The Power Gas Corporation, Ltd., set aside a department within its organisation at Stockton-on-Tees to co-ordinate all this work in several departments in order to provide a close and constant link with the Government of India representative in the United Kingdom, with the Chemical Construction Corporation, and with the many other contractors concerned.

A new office was set up by the firm in Calcutta under the direction of a manager, with three or four picked men from Stockton to train and advise Indian staff recruited locally. This office was responsible for ordering a large amount of equipment made in India, the largest part of which was nearly 15,000 tons of structural work for buildings, supports, &c. It also dealt with all the remaining equipment which had to be imported from abroad and which involved the handling of nearly 45,000 tons of plant, amongst which there were four pieces each weighing 95 tons. A number of bulky units which could not be transported by rail had to be dispatched by barge up the Ganges as far as Patna, and carried from there to the site by road, through mountainous country, over a selected and prepared route.

At the site there was established what



POWER STATION AT SINDRI

became the largest organisation set up by the firm in connection with this contract. It consisted of a chief resident engineer, assisted by a number of British mechanical and electrical engineers, skilled foremen and staff, to direct the Indian staff and foremen engaged locally. The amount of work and the organisation involved in carrying out the project will be appreciated when it is pointed out that more than 250 firms were directly engaged in carrying out work or supplying materials and equipment.

Work on the site was started early in 1945 and in its preparation some 120,000 cubic yards of earth were moved in laying out the 350 acres required for the factory. In the construction of the plant buildings, foundations, &c., 91,000 cubic yards of concrete were placed and 11,000 tons of structural steel erected, whilst the actual plant installed weighed about 45,000 tons. For the services 80 miles of pipeline and 170 miles of power cables were laid, together with 7 miles of belt conveyors. Raw materials, coal, &c., are brought to the site by rail, and sidings with some 12 miles of track have been laid down for the factory and marshalling yards. The comprehensive transport system required will be appreciated when it is explained that the incoming raw materials daily are as follows :—800 tons of coal, 600 tons of coke, 1800 tons of gypsum, and 400 tons of other materials. Outgoing finished products include 1000 tons of ammonium sulphate and 300 tons of cement daily, together with 1200 tons of by-products and waste. When the factory is in full production there will be six incoming and six outgoing trains daily handling the raw materials and products.

Early in the project it was decided that some 12 million gallons of water would be required daily to run the proposed plant, whilst for several months of the year the surface supply from the Damodar River was well below 5 million gallons. For this reason major works were carried out in the area to ensure an adequate water supply throughout the year. Those works involved the construction of a barrage on the Gowai River, a tributary which joins the Damodar about 4 miles upstream of Sindri, and the building of an infiltration gallery to tap the water available in the sands of the Damodar bed when the surface supply diminishes. This barrage on the Gowai has created a lake of between 800 and 1000 million gallons of water, which during dry weather passes into the infiltration galley of the plant.

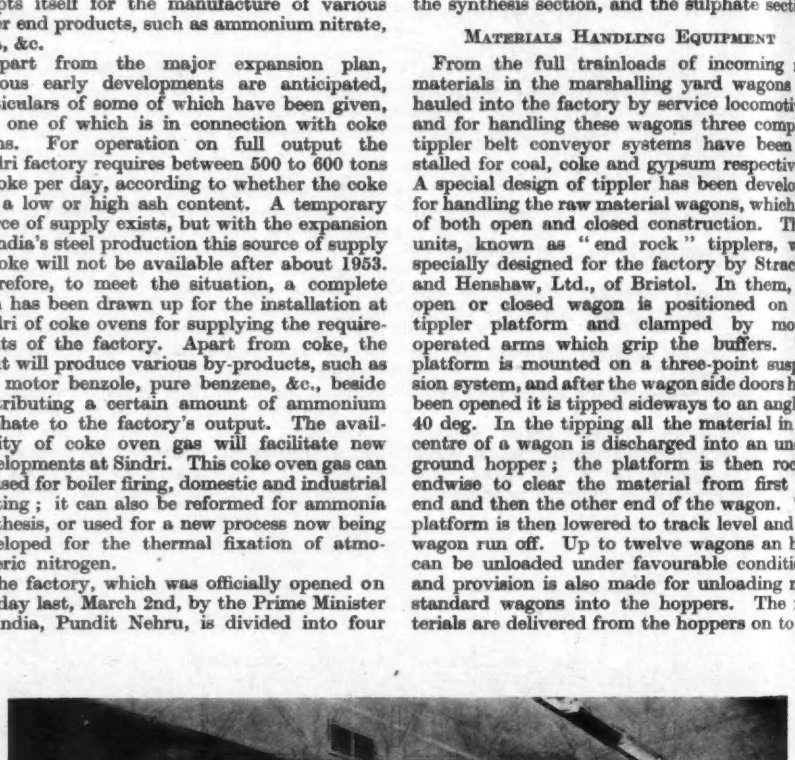
The Sindri factory itself has been planned to facilitate expansion to double its present size. Buildings have been laid out in such a way that, in the event of expansion, everything will be in the right place. All underground services, such as water supply mains, sewers, &c., have been installed to permit doubling of capacity. The expansions contemplated do not necessarily mean the doubling of the production of ammonium sulphate, for the layout adapts itself for the manufacture of various other end products, such as ammonium nitrate, urea, &c.

Apart from the major expansion plan, various early developments are anticipated, particulars of some of which have been given, and one of which is in connection with coke ovens. For operation on full output the Sindri factory requires between 500 to 600 tons of coke per day, according to whether the coke has a low or high ash content. A temporary source of supply exists, but with the expansion of India's steel production this source of supply of coke will not be available after about 1953. Therefore, to meet the situation, a complete plan has been drawn up for the installation at Sindri of coke ovens for supplying the requirements of the factory. Apart from coke, the plant will produce various by-products, such as tar, motor benzole, pure benzene, &c., beside contributing a certain amount of ammonium sulphate to the factory's output. The availability of coke oven gas will facilitate new developments at Sindri. This coke oven gas can be used for boiler firing, domestic and industrial heating ; it can also be reformed for ammonia synthesis, or used for a new process now being developed for the thermal fixation of atmospheric nitrogen.

The factory, which was officially opened on Sunday last, March 2nd, by the Prime Minister of India, Pundit Nehru, is divided into four main sections : the power plant, the gas plant, the synthesis section, and the sulphate section.

Materials Handling Equipment

From the full trainloads of incoming raw materials in the marshalling yard wagons are hauled into the factory by service locomotives, and for handling these wagons three complete tippler belt conveyor systems have been installed for coal, coke and gypsum respectively. A special design of tippler has been developed for handling the raw material wagons, which are of both open and closed construction. These units, known as "end rock" tipplers, were specially designed for the factory by Strachan and Henshaw, Ltd., of Bristol. In them, the open or closed wagon is positioned on the tippler platform and clamped by motor-operated arms which grip the buffers. The platform is mounted on a three-point suspension system, and after the wagon side doors have been opened it is tipped sideways to an angle of 40 deg. In the tipping all the material in the centre of a wagon is discharged into an underground hopper ; the platform is then rocked endwise to clear the material from first one end and then the other end of the wagon. The platform is then lowered to track level and the wagon run off. Up to twelve wagons an hour can be unloaded under favourable conditions, and provision is also made for unloading non-standard wagons into the hoppers. The materials are delivered from the hoppers on to the



POWER STATION CONTROL ROOM

feed belt conveyor system by electro-magnetic vibrating feeders. Provision is made for feeding materials from the stock piles into the main hoppers when required.

The Power Plant

The power station, which is to be seen in one of the photographs we reproduce, has an installed capacity of 80,000kW, some 40,000kW of which are expected to be consumed in the process plant, 15,000kW to 20,000kW being available for distribution to the grid system which is to be coupled to the factory, and the remainder will serve as standby equipment.

The whole of the steam-raising installation was supplied by Babcock and Wilcox, Ltd. The boiler plant consists of six tri-drum units, each having a steaming capacity of 175,000 lb per hour at 650 lb. per square inch and 835 deg. Fah.

The fuel—a low-volatile coal hitherto considered unsuitable for steam raising—is burned by "Rotograte" spreader stokers with forward-running grates. In this type of stoker coal is fed from a hopper to a revolving rotor, which flings it towards the back of the furnace, combustion taking place partly in suspension, partly on the moving grate. Since the energy given to each piece of coal is directly proportional to its weight, the larger pieces travel further than the smaller, thus giving uniform distribution, while the forward-running grate ensures that the heavier particles remain longer in the furnace, thus ensuring complete combustion. This kind of stoker, with a comparatively thin uniform fire, gives very rapid response to changes in load, and has the ability to deal with a wide range of fuel. Grit refiring is provided to deal with small particles of fuel; the grit is also collected in hoppers near the economiser and air heater, and returned for refiring. Air-operated automatic combustion control is provided.

The twin multi-loop pendant superheaters have surface attemperators between the primary and secondary superheaters for control of final steam temperatures over a wide load range.

Economisers are provided and the feed temperature is 320 deg. Fah. The air heaters are three-pass cross-flow tubular units, and hand-operated soot blowers are installed.

The six turbo-alternators in the station were built by C. A. Parsons and Co., Ltd., and they generate three-phase current at 11kV, 50c/s. There are two 12,500kW back-pressure units and four 15,000kW condensing units. These units operate on a 600 lb per square inch stop valve pressure and a temperature of 825 deg. Fah., the back-pressure sets exhausting at 25 lb per square inch and the condensing sets at a vacuum of 27in.

All of the main station electrical controls are installed in the air-conditioned control room, to be seen in one of our illustrations. The equipment in this section for controlling the generators, transformers and feeders was all supplied by the English Electric Company, Ltd., which also supplied most of the motor drives in the new factory. The switch-gear consists of a twenty-five panel, totally enclosed, floor mounting, horizontal draw-out isolating, metalclad switchboard, arranged for double busbar service, solenoid operation, on-load busbar selection, and it has a breaking capacity of 1000MVA at 11kV.

The switchboard is divided into three sections. The first section of ten panels covers three generators, five feeders, one reactor, and a single bus coupler; the second section of eight panels covers two generators, one reactor, four feeders, and a busbar coupler; and the third section of seven panels one generator, one reactor, four feeders, and a bus coupler. Each section of the main switchboard is interconnected by a reactor which is arranged to limit the short-circuit rating when all generators are operating in parallel. These reactors are accommodated in chambers immediately below the 11kV switchgear, to which the connections are made through air-insulated conductors assembled in totally enclosed built-up sheet steel chambers.

Provision for isolating the reactors is made by means of remote manually operated isolating switches mounted on the chambers. The control of the main 11kV switchboard is effected through a separately mounted control and relay switchboard. This built-up steel cubicle switchboard is arranged in corridor form, the indicating and recording instruments and mimic diagram being mounted on the front of the panels, whilst the ancillary apparatus is mounted on the rear set of panels. Access is given to the rear of each set of panels by means of a centre corridor.

On the 11kV side of the substation transformers, also supplied by the English Electric Company, Ltd., there are vertical break outdoor isolating switches arranged for operation from ground level. Each isolating switch is interlocked with the associated oil circuit breaker on the main switchboard in order to ensure a correct sequence of operation. This equipment incorporates the current transformers required for the protection of the substation transformers.

For the control of the power station auxiliaries a seventeen-panel totally enclosed, floor-mounted, air insulated, airbreak switchboard has been installed. It is a single busbar unit, arranged in two sections and interconnected by means of a bus section breaker. The airbreak circuit breakers are suitable for use on 3300V, three-phase, 50 c/s supply system and are arranged for horizontal isolation. The transformer and bus section panels are arranged for solenoid operation and are provided with interlocks to prevent the bus section circuit breaker being closed at the same time as the transformer breaker. Where 400V supplies are required in the power station and substations suitable airbreak switchgear is provided.

Power is distributed to twelve substations in the plant at 11kV by cables carried on racks in trenches with removable covers. The whole of this power cable installation, together with its ancillary equipment, was carried out by British Insulated and Callender's Cables, Ltd. It involved the installation of some 5 miles of 11kV cable, 7 miles of 3300V cable, and 128 miles of low-voltage cable. The orders for the 3300V and 400V distribution equipment were placed with Reyrolle and Co., Ltd.

A comprehensive plant, yard and roadway lighting system which is necessary to enable the plant to work a twenty-four-hour day, has been installed by the General Electric Company of India, Ltd.

(To be continued)

Fulham Power Station

The full capacity of Fulham power station, 360MW, was reached by the end of last year when the sixth generating set was brought into service. This set, which was formally commissioned by the Mayor of Fulham on Wednesday, March 5th, differs from the earlier sets in a number of ways. It runs at 3000 r.p.m. and has a gear-driven exciter. Initially, the steam conditions will be 600 lb per square inch and 800 deg. Fah., but the three-cylinder turbine is so designed that it can be modified for operation at 900 lb per square inch and 900 deg. Fah. if higher steam conditions become desirable. A short description of the station is given herewith.

FULHAM power station occupies a site of 12¼ acres between Townmead Road and the north bank of the River Thames. The site was originally developed in 1901 when Fulham Corporation built a power station for supplying electricity to consumers within the municipal boundaries. Because of the natural advantages of this site the former Central Electricity Board came to an agreement whereby the Corporation built a completely new station with an output greatly in excess of local requirements, so that the surplus could be fed to the grid. Since the new station began operation in 1936, its capacity has been increased at intervals, and it is now fully developed at 360MW, which is made up of six 60MW sets.

Coal supplies are brought by the British Electricity Authority's 2000-ton colliers, to a coaling jetty 350ft long and 35ft wide. Unloading is carried out on the jetty by three portal cranes which discharge coal on to duplicate belt conveyors delivering 200–300 tons per hour either direct to the bunkers or to two silos having a combined storage capacity of 80,000 tons.

There are two boiler-houses on the north-eastern portion of the site. Each contains eight Stirling tri-drum boilers arranged in two rows of four with a central firing aisle. In one group each of the eight boilers has a maximum continuous rating of 260,000 lb of steam per hour; in the other group the corresponding figure is 315,000 lb per hour. The steam conditions at the superheater stop valves are 625 lb per square inch and 850 deg. Fah. The superheaters are "Melesco" controlled equipments, consisting of primary and secondary sections separated by desuperheaters which provide a by-pass for the steam. Automatic superheat control is maintained thermostatically by the Hagan (James Gordon) compressed air operated system in the case of eleven of the boilers, and by George Kent controllers embodying Selsyn units in the other five boilers.

Water-cooled Bailey walls form part of the boiler circulating system. Firing is effected by Taylor multiple-retort gravity underfeed stokers, the speed being controlled from the boiler control panel. Each boiler has two Howden Ljungstrom regenerative air heaters in which the hot gases and the incoming air pass in opposite directions through separate halves of slowly revolving multi-plate elements. There are also two forced draught fans, two induced draught fans and two secondary air fans for each boiler, the output of air being regulated by Howden-Tate vanes or by hydraulic couplings.

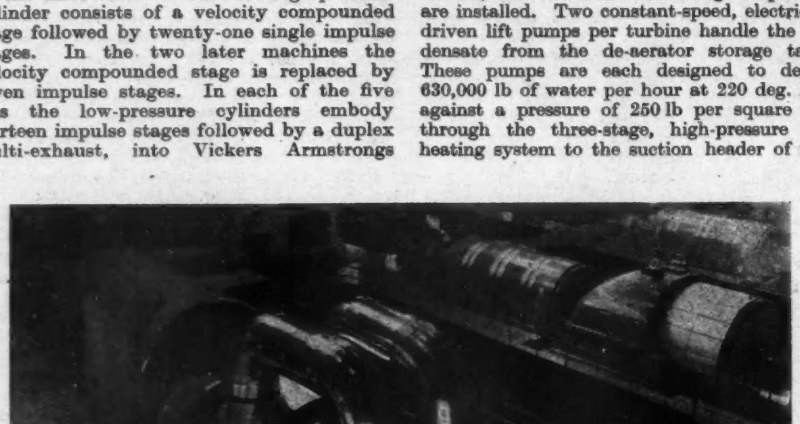
Automatic control of the feed water supply is provided by Weir "robot" or Copes regulators. Foster Green economisers are installed in association with the smaller boilers and Senior economisers with the larger.

Although a comprehensive system of soot blowing is installed, water lancing on load is preferred for the front bank of boiler tubes and the superheater tubes. Coarse grits in the gases from the combustion chamber are deposited in hoppers below the boiler passes, where the gases change direction, and are returned to the furnace, the residue being finally exhausted from the hopper under vacuum. Ultimately, grits are collected between the preheater gas exit and the induced draught fan inlets by Howden "Centi-cell" arrestors whence the residue is transferred to storage bunkers. Arrangements are also made for returning to the bunkers riddlings that have dropped through the grates.

Ash removal is by Babcock and Wilcox sluicing from hoppers behind the grates to a central receiving pit and thence to reinforced concrete bunkers for final disposal by lorries. The ash and grit bunkers lie between the boiler-house and the river bank.

On the other side (north-east) of the boiler-house is the feed pump bay, and beyond that the turbine house, in which the six sets are arranged side by side as suggested by one of the photographs reproduced overleaf. The first five turbo-alternators are Metropolitan-Vickers 1500 r.p.m. sets with a maximum continuous rating of

60MW. The initial steam conditions are 600 lb per square inch and 800 deg. Fah. In the three older turbines the high-pressure cylinder consists of a velocity compounded stage followed by twenty-one single impulse stages. In the two later machines the velocity compounded stage is replaced by seven impulse stages. In each of the five sets the low-pressure cylinders embody thirteen impulse stages followed by a duplex multi-exhaust, into Vickers Armstrongs regenerative condensers which are made in two halves supplied by independent circulating water pumps. The circulating water requirements for the whole station total 15 million gallons of water per hour.



No. 6 Turbo Alternator Set

The Sixth Turbo-Alternator

The sixth set exhibits some important design differences from the five earlier sets. It has the same rating of 60MW, but it was manufactured by the English Electric Company, Ltd. Its speed is 3000 r.p.m. and its exciter is driven through reduction gearing instead of being direct-coupled like the exciters of the 1500 r.p.m. sets. Another difference is that the alternator of the new set is hydrogen cooled.

Perhaps the most interesting difference, however, is that, although the turbine will operate initially with steam at 600 lb per square inch and 800 deg. Fah., it is designed so that it can be modified to operate at 900 lb per square inch and 900 deg. Fah. if and when the existing boilers are replaced by others generating steam at the higher steam conditions. Accordingly, the turbine is of three-cylinder design, but, for the present operating conditions, the first few rows of blades and nozzles at the high-pressure end have been omitted.

To provide space for the new set a 10MW house set which had become virtually redundant under present operating conditions, was removed. At the same time, the circulating water intake capacity had to be increased by building a second screen house at the river intake. Besides serving the sixth set the new screen house gives a reserve of screening capacity for the whole station, a facility which is useful in the autumn when the screens are liable to be choked by dead leaves. On the outlet side of the circulating water system a separate 54in discharge pipe was built from the condenser via the turbine room basement and the north roadway to the river outfall just downstream of the old screen house.

For feed-heating purposes each turbine is provided with a low-pressure heater, a gland heater, a de-aerating heater and three high-pressure heaters supplemented by ejector coolers, and double effect interstage evaporators are installed. Two constant-speed, electrically driven lift pumps per turbine handle the condensate from the de-aerator storage tanks. These pumps are each designed to deliver 630,000 lb of water per hour at 220 deg. Fah. against a pressure of 250 lb per square inch through the three-stage, high-pressure feed heating system to the suction header of final boiler feed pumps. These Mather and Platt pumps are electrically driven through hydraulic couplings for variable-speed control, and each can pump 630,000 lb of water per hour at 358 deg. Fah. against a total pressure of 800 lb per square inch (absolute), the suction side pressure being 215 lb per square inch (absolute). For emergency use there are three turbine-driven pumps.

Electrical Arrangements

The first three alternators were designed to work at 0·8 power factor and the next two machines, with a stronger field, at 0·9 power factor. Their stator windings are star connected and they have a sub-transient reactance of 17 per cent based on 75MVA. Cooling of the first five alternators is by a closed air circuit fan system with tubular intercoolers, which take their cooling water from the circulating water pump discharge. On each of the first five sets the exciters are quick-response machines with a ceiling voltage of twice the normal value; the exciter fields are fed by overhung shunt wound pilot exciters. If the voltage of the alternator should fall to 80 per cent of normal under fault conditions, its excitation is automatically boosted to 150 per cent of normal until the alternator voltage has been raised to 95 per cent of normal.

A 75MVA delta-star transformer (oil immersed, with forced oil circulation and water cooling) is connected direct to each alternator to step up its output from 11kV to 66kV at the grid substation. The transformers are protected by Buchholz gas-operated relays. Further protection is provided by winding temperature indicators with audible alarm. The connections from the transformers to the alternators are made by copper tubes, insulated by bakelised paper, and to the main switchgear by Henley's single-core, oil-filled, paper-insulated cables. The whole unit, comprising alternator, transformer and cables, is protected on the Merz-Price circulating current system.

The 66kV main switchgear is Metropolitan-Vickers oil-immersed, metal-clad, duplicate busbar equipment, arranged in four sections, each controlling an alternator-transformer, a section reactor and four feeders. Each 800A phase-separated circuit breaker has two breaks per pole with cross-jet explosion pots. The rupturing capacity is 1500MVA.

A total load of about 12,500kW is taken by works power, lighting and heating, and by the canteens, which are all-electric. The supply comes from two 15MVA, 66kV/6·6kV delta-star transformers fitted with on-load, tap-changing gear. One house transformer is direct connected to a 6·6kV switchboard equipped with metal-clad duplicate busbar, 1200A oil circuit breakers with a rupturing capacity of 250MVA. It is linked with another switchboard through two 12·5MVA cast-in-concrete reactors, having a 7 per cent reactance. The second switchboard, which embodies similar circuit breakers, but rated at 300A and 150MVA, is fed from the second house transformer through a 15MVA reactor of 8·4 per cent reactance.

Between the 66kV switch-houses and the turbine room, and forming a bridge over a roadway between them, is the main control room. As illustrated herewith, control panels form three sides of a square, with the control engineer's desk and mimic diagram at the middle of the fourth side. The generating sets have sectionalised desk control panels in front of their respective instrument panels and facing the control engineer's desk. Protective relays are mounted on panels separate from the instrument panels. In addition, the alternator sets have separate panels accommodating automatic voltage regulators and associated relays. All control panels for the feeders are arranged in sections corresponding to the switchgear they

Control Room

control, as are the feeder protective gear panels. Each section reactor panel is alongside the alternator panel associated with the same switchgear section.

Above the control panels there is a mimic diagram, equipped with lamps showing whether circuit breakers are closed, open or withdrawn, and showing the position of the voltage transformer and circuit-earthing switches. The controls for the 6·6kV side of the house transformers and the 6·6kV reactors for the station auxiliaries are installed next to the indicating panels for the fire-fighting equipment.

There are two synchronising panels, each comprising a 12in synchroscope, together with "incoming" and "on-load" voltmeters and synchronising relays. Above these panels are the busbar voltmeters. No circuit breaker can be closed without first inserting synchronising plugs both in the sockets of the synchronising panel and of the panel controlling that circuit breaker, and selecting the volts by inserting the appropriate plug in the voltage socket for any circuit breaker already switched to that section of busbar with which it is desired to synchronise. Each synchronising panel is equipped with a relay energised from the selected "incoming" and "on-load" voltage transformers, which will close the circuit to the synchronising plugs and circuit breaker control switches only, when the incoming circuit is very close to synchronism. Relays are provided to enable "live" circuits to be switched to "dead" busbars, and "dead" circuits to "live" busbars. Circuits having phase displacement can be closed in emergency. A flashing green light on the mimic diagram for the circuit breaker concerned, accompanied by a pulsating buzzer, indicates automatic tripping.

Overall Thermal Efficiency

Fulham power station is in the London Division of the British Electricity Authority. During the past three years the station has sent out to the system 1590 million, 1725 million and 1571 million units, the maximum loads (sent out) being 298·2MW, 301·4MW and 289·8MW. The corresponding overall thermal efficiencies were 26·35, 26·70 and 26·49 per cent. The figure of 26·70 (sent out) obtained in 1948 was the highest for all stations in Great Britain in that year.

Books of Reference

The Electrician Blue Book Electrical Trades Directory, 1952. Edited by S. G. Rattee, A.M.I.E.E., and F. J. Harper. London: Benn Brothers, Ltd., 154, Fleet Street, E.C.4. Price £2 10s.—The seventieth edition of this well-known and widely-used directory of the British electrical and allied industries is arranged on similar lines to the previous volumes. Each of the twelve main sections covering the activities of every branch of the industry and associated professional and trading organisations has been carefully revised and brought up to date. The scope of the classified section of products has been extended by the introduction of many new headings, and these additions, together with those made to the trade names section, have increased the size of the book by some seventy-five pages. As in former editions, the information given is both comprehensive and authoritative, and its arrangement makes for quick and easy reference by users.

The Directory of Shipowners, Shipbuilders and Marine Engineers, 1952. London: Tothill Press, Ltd., 33, Tothill Street, Westminster, S.W.1. Price 40s.—The recent issue of the *Directory of Shipowners, Shipbuilders and Marine Engineers* 1952, marks the fiftieth edition of the work, which continues to provide, in convenient form, information concerning the world's principal shipowning and shipbuilding companies. Extensive revisions have been made to the various sections, which appear as in previous years, and include particulars of the fleets of shipping lines and details of capacity and personnel of shipyards at home and abroad. There is a comprehensive list of consulting naval architects and marine engineers and also of trade and technical organisations, while details of the classification societies are given, followed by an official appendix covering Government departments. Five indexes are included in the volume, giving names of ships, names of companies, and telegraphic addresses, followed by a general index, and a personal index.

Gear-Tooth Stresses and Rating Formulæ*

By H. E. MERRITT, M.B.E., D.Sc. (Eng.), M.I.Mech.E.†

No. 1

Introduction

Gears have not the glamour of an impressive prime mover or the fascination of a complex automatic machine, but they are indispensable—and, it is hoped, unobtrusive hand-maidens to mechanical engineering; they rank with the fundamental inventions of the wheel and the screw. It has been estimated that the value of present annual production of gears and gear units in Great Britain is around £100 million.

But gear units have one feature which is perhaps unique amongst machines, in that the overall dimensions, weight and cost directly reflect the choice of working stresses at one point—the critical point of contact between the teeth. Hence, a small average increase in permissible tooth loading could represent a very large annual saving in material and manufacturing effort. It is therefore of considerable economic as well as technical importance to consider the present state of knowledge, and to examine the consistency of the methods and of the empirical factors which enter into current methods for comparing gear-tooth stresses and determining permissible loading. The notation used in calculations is shown in a footnote on this page.

The Present State of Ignorance

The catalogue of the items entering into gear design, on which knowledge is either inadequate or totally lacking, is impressive. The gaps must be filled by empirical data or by guesses, more or less inspired. Present methods of stress comparison, and rating formulæ, have been evolved over many years; on average, they give reasonably satisfactory results and it is unlikely that any responsible gear designer would accept with confidence a drastic departure, based purely upon theoretical considerations, from present methods. More certain progress is likely to come from revision of details in the light of experience, and from a search for a better understanding of the fundamental mechanism of sliding rolling contact and of the properties of materials under repeated stress.

It is not to be inferred that this shortage of detailed knowledge is peculiar to gear design or to the gear designer. On the contrary, the gear specialist is often asked to put forward proposals for gears to drive a machine, when the maximum horsepower or torque required are unknown by its makers. He must then exercise judgment and take decisions which demand intuitive knowledge and practical experience of a high order.

But even when the mean transmitted load is accurately known, the actual forces between the teeth of gears are often uncertain; the nominal mean tooth load may be cyclically increased by external torsional vibrations or by internal dynamic increments arising from errors of tooth form. Moreover, even in circumstances in which dynamic or other cyclic increments are absent, the maximum intensity of local loading may drastically exceed the mean value, owing to maldistribution of surface pressure over the profile or across the face width.

The cause of this maldistribution may lie in errors of cutting, mounting, or alignment of the gears; deflection of gears, shafts, bearings, or casings under load, and temperature changes. To minimise these effects by profile modification and tooth spiral modification is part of the art of gear cutting, an art on which the demands increase as design is refined in the quest for higher load-carrying capacity.

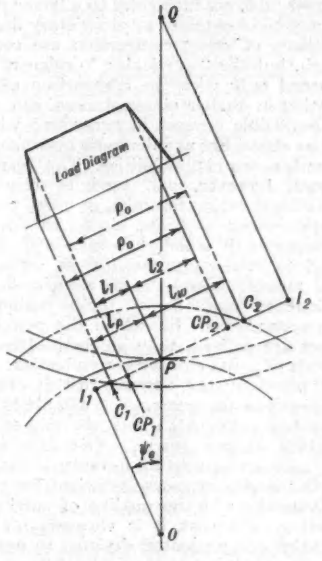


FIG. 1—*Chosen Load-points for "Precision" Gears*

When the local intensity of loading is known, however, many uncertainties surround the stress conditions that will lead to failure of a given material or combination of materials. The conventional generic names for the two broad categories of tooth resistance are "wear resistance" and "strength." "Wear" includes all forms of surface breakdown, whether sub-surface failures such as pitting or exfoliation, or surface failures such as scuffing and scoring. Pitting, loosely thought of as a simple form of fatigue failure caused by stress alone, is more complex; Meldahl (1941)‡ showed by experiment, and experience confirms, that it is not merely due to compressive stress, but largely depends upon relative surface motion in the presence of lubricant, with the inference that it involves tangential (frictional) forces, temperature changes (Blok, 1937), thermal conductivity, the hydro-dynamic properties of the oil film, and the propagation of hydraulic pressure in cracks (Way, 1935).

Tooth breakage is nearly always a fatigue failure, but the comparative resistance of different gear materials under the conditions of tooth loading remains only partially explored.

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* Institution of Mechanical Engineers, February 29th.

† Chief administrative engineer, Humber Ltd., Coventry.

Notation

C	Centre distance.
D	Pitch diameter of wheel.
d	Pitch diameter of pinion.
E	Modulus of elasticity.
F	Tangential load.
F_c	Normal tooth reaction per inch of length of contact line.
F_i	Tangential load at the pitch circles per inch of face width.
f	Face width.
h	Addendum reduction (topping) to give adequate bottom clearance.
I	Centre of curvature of engaging involute (spur gear).
K_{adj}	Adjusting constant.
k	Addendum coefficient.
l	Distance of any selected point of contact from the pitch point.
l_t	"Tangent-length."
M	Torque.
N	Speed of wheel, r.p.m.
n	Speed of pinion, r.p.m.
P	Diametral pitch.
p	Circular pitch.
R	Radius of curvature.
R_r	Relative radius of curvature.
r	Inverse ratio $= \frac{t}{T}$.
S	Stress.
T	Number of teeth in wheel.
t	Number of teeth in pinion.
U	Running time.
U_{eq}	Equivalent running time.
V	Pitch circle velocity, feet per minute.
V'	Sliding velocity.
X	Speed factor.
Y	Strength factor.
Z	Zone factor.
θ	Angle of inclination.
μ	Coefficient of friction.
α	Spiral angle.
ϕ	Pressure angle.

Suffixes (general)

b bending; c surface; e engagement; g generation; h helical gear; o basic; p pinion; w wheel; vs virtual spiral gears; $_{1,2}$ distinguishing two values.

‡ An alphabetical list of references is given in the appendix to the paper.

Almen (1935 and 1950) and Almen and Straub (1937) have extensively investigated the properties of case-hardened gears for automobile transmissions, but the materials used for industrial gears offer scope for more work, particularly in the interests of low initial cost of material and in avoidance of expensive or unobtainable alloying elements.

In regard to both strength and wear resistance, no useful data—that is, data which can be quantitatively applied to practical design—seem available on the effect of cyclic variation of load or the scale effect, and in regard to strength, on the effect of fillet curve shape on endurance. Unfortunately, tests on actual gears introduce so many variables that the results can seldom be conclusive, and the relatively small proportion of gears that fail or give trouble in service are an even less dependable source of accurate information. It is to be hoped, therefore, that more controlled laboratory experiments will be undertaken; the rewards for the effort could be very great.

Design Categories

Gear design may be divided into two categories, each requiring its own methods of stress comparison: the particular, involving the design of gears limited in variety, type and size, as integral parts of more complex machines manufactured domestically (and usually in quantity), and the general, in which the gears, or a gear unit, are incidental to a larger project and may be of external or proprietary design.

Methods of stress comparison are common to both, but the "particular" designer, being concerned only with the comparison of gears operating in similar circumstances, can adjust his permissible stresses in agreement with his peculiar experience and domestic manufacturing circumstances and possibilities. The "general" designer, however, will tend to rely upon standardised rating formulæ, in order to cover the wide range of types, sizes and operating conditions with which he deals and, significantly, to achieve uniformity in estimating.

As rating formulæ are associated with standardised methods of tooth design and incorporate factors by which the permissible stresses are defined, they go further than the methods of stress comparison embodied. They are typified by the current British Standard Specifications for gears, No. 436 : 1940 (spur and helical), No. 545 : 1949 (bevel), and No. 721 : 1937 (worm gears). The inference in using standardised rating formulæ is that they include margins of safety sufficient for reasonable variations in the quality of cutting and mounting, and that it is cheaper, for small quantities or unrepeated designs, to use more material on a job that must "work first time" than to develop a lighter design having the utmost load-carrying capacity; and circumstances may justify this course.

Tooth Design

Involute tooth forms offer infinite choice, but after a lengthy evolution, characterised by steady increase in pressure angle, tooth designs based on generation from an imaginary rack having a pressure angle of 20 deg. are probably in the majority, if not yet universal. As wide latitude is still available, by the artifice of "correction" or "addendum modification," it is necessary to state the tooth forms with which this paper deals.

The radial dimensions of a tooth and the relative position of the opposed involutes which bound it are determined, given a symmetrical imaginary rack, by the radial displacement of the axis of symmetry of the rack from the pitch circle of generation of the gear, expressed as a fraction of the module (the reciprocal of the diametral pitch). This quantity, which the author originally called the "correction coefficient" (now termed "addendum coefficient" in B.S. 545 : 1949) is denoted by k_p for the pinion and k_w for the wheel. The term "imaginary rack" is here used to distinguish it from the "basic rack," the profile of which is modified to provide tip easing and completed by the radii which generate the fillet curves.

Three varieties of tooth can be generated from such a rack, namely:

(1) Those which have no addendum modification on either gear and work at the standard centre distance.

(2) Those in which the pinion and wheel have equal and opposite addendum coefficients—that is, they have zero algebraic sum, and work with pitch diameters and a pressure angle corresponding to those of generation.

(3) Those in which the sum of the addendum coefficients is not zero. It is usually positive in such cases, and the gears work at pitch diameters and at a pressure angle greater than those of generation.

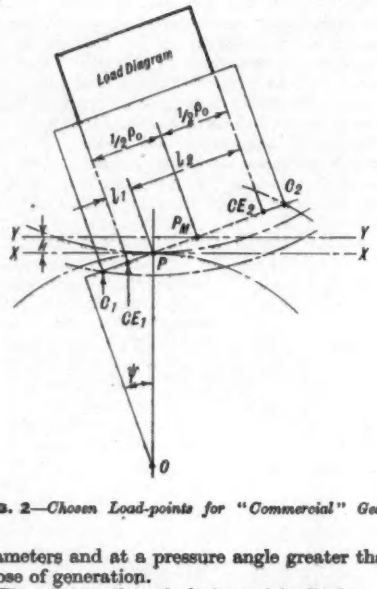

FIG. 2—*Chosen Load-points for "Commercial" Gears*

The system of tooth design originally formulated by the author and embodied in B.S. 436 : 1940 is as follows. For a tooth sum of 60 or more, $k_p = 0{\cdot}4(1-r)$ and $k_w = -k_p$ (where r is the inverse ratio t/T); but if t is less than 30, k_p is made not less than $0{\cdot}02(30-t)$. When the tooth sum is less than 60, the sum of the addendum coefficients is made equal to $0{\cdot}02[60-(t+T)]$; but this disturbs the amount of tip easing generated by a British Standard basic rack and the assumptions made in this paper in regard to the conditions of tooth loading are no longer applicable.

In regard to helical gears, the addendum coefficient is calculated and applied with reference to the virtual spur gears on the normal section; if σ is the spiral angle, the numbers of teeth in the virtual spur gears are

$$t_{vs} = t \,.\, \sec^3 \sigma \text{ and } T_{vs} = T \,.\, \sec^3 \sigma.$$

When dealing with "precision" gears from which the maximum of load-carrying capacity is sought (applying chiefly to heavily loaded case-hardened gears) the kind of profile modification produced by a British Standard basic rack is inadmissible and the controlled profile modification which this case requires has been investigated at length by Dr. Harry Walker (1938, 1940, 1944, 1946). The advantages of a pressure angle greater than 20 deg. can be shown by a calculation and have been demonstrated in practice, and a simple basis of tooth design which gives well-balanced proportions is obtained when both pinion and wheel have an addendum coefficient of $+0{\cdot}5$.

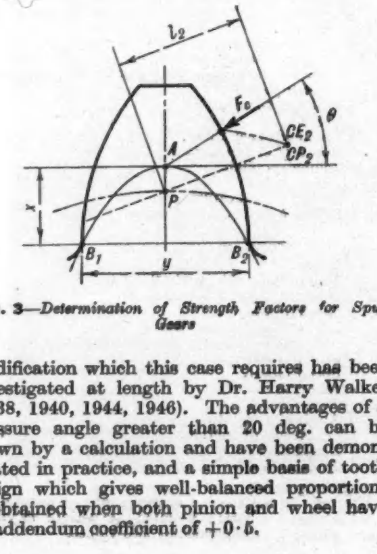

FIG. 3—*Determination of Strength Factors for Spur Gears*

Gears thus designed work at a pressure angle given by

$$\text{inv } \psi_c = \frac{2 \tan \psi_g}{(t+T)} + \text{inv } \psi_g,$$

where inv ψ_c = "involute function" of ψ_c = $\tan \psi_c - \psi_c$ (radians), and at a centre distance

$$C_c = C \,.\, \cos \psi_g \,.\, \sec \psi_c,$$

where ψ_g and ψ_c are the pressure angles of generation (20 deg.) and engagement respectively, C_c is the centre distance of engagement, and C the centre distance at which the same tooth combination would engage if there were no addendum modification. In order to avoid too small a bottom clearance, whilst keeping the tooth form for a given number of teeth the same throughout, the teeth are "topped" by reducing the addendum by the amount k given in Table I (which applies to teeth of 1 diametral pitch).

These two systems of tooth design, of course, by no means exhaust the possibilities, and many others have been put forward. They have been selected for the purposes of this paper to provide a basis for the re-computed strength and zone factors here given; the brief statement of each is intended only to define the tooth forms thus examined and not to provide full details of tooth design.

TABLE I.—*Topping of Teeth by Reducing Addendum*

t	k	t	k	t	k	t	k
10	0·17	14	0·13	18	0·09	25–9	0·05
11	0·16	15	0·12	19	0·08	30–4	0·04
12	0·15	16	0·11	20	0·07	35–9	0·03
13	0·14	17	0·10	21	0·06	40–4	0·02

The "Chosen Load-Points"

Any analysis of "strength" or "wear resistance" must begin with the choice of the points at which the intensity of stress is assumed to be at its most unfavourable.

"*Precision*" *Gears.*—This description is here applied to gears having teeth finished by a profile-grinding, or other precision finishing operation, to a form of which the profile modification, or departure from the theoretical involute, is precisely specified and controlled. The amount of modification will be based upon considerations of tooth-deflection (Walker, 1938, 1940) rather than of probable pitch errors, which will be small in comparison with deflection.

With these gears the object is to secure a load-variation on a particular pair of teeth throughout the cycle of engagement of the order illustrated in Fig. 1. Here P represents the pitch point and ψ_c the pressure angle of engagement, and C_1C_2 the path of contact terminating at the addendum circles. By appropriate choice and control of the profile modification, a tooth-load increasing uniformly from zero at the extremities of the path of contact to a maximum at the change-points CP_1 and CP_2 is sought; the change-points are the points at which contact changes from one to two pairs of teeth and are distant one base pitch (p_c) from the ends C_2 and C_1, respectively. The change-points are therefore the chosen load-points for this case.

The respective positions of these points, measured from the pitch point, are given by

$$l_1 = l_p - \pi \,.\, \cos \psi_g$$
$$l_2 = \pi \,.\, \cos \psi_g - l_w$$

where l_p and l_w are the lengths of the path of face contact of the pinion and the wheel respectively and ψ_g is the pressure angle of generation if different from that of engagement; and in this and all other cases here considered and illustrated, the pitch is taken to be 1 diametral pitch.

"*Commercial*" *Gears.*—This description is here applied to gears generated from a hob, or from a cutter of rack form, corresponding in profile to the basic rack, class A2 or B, defined in B.S.436 : 1940. It is a characteristic of this basic rack that the points at which tip-easing begins (taking pinion and wheel together) are distant one base pitch apart; that is, they give one base pitch of involute contact, symmetrically disposed with reference to the axis of symmetry of the basic rack teeth.

This condition is illustrated in Fig. 2, in which P is the pitch point, XX the pitch line of generation of the basic rack, and YY its axis of symmetry. The nominal path of contact is C_1C_2, but CE_1 and CE_2 are the extreme points of involute contact, each distant one-half the base pitch from the point of symmetry P_M of the basic rack.

For the purposes of the present analysis, CE_1 and CE_2 will be taken as the chosen load-points for this case. A complicated argument is possible, of course, about the probable effect of errors of pitch and profile, and about the result of using gear-shaper cutters with their uncertain and, in any event, variable profile modification; but as a basis for purely comparative estimates of load-carrying capacity,

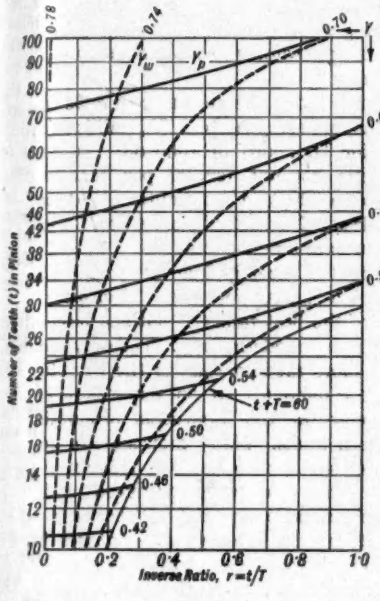

FIG 4.—*Chart of Strength Factors for "Commercial" Spur Gears*

it seems doubtful whether further refinement of assumption is justifiable.

The respective distances of CE_1 and CE_2 from the pitch point are given by

$$l_1 = \tfrac{1}{2}t \,.\, \sin\phi + k \,.\, \operatorname{cosec}\phi - \tfrac{1}{2}\pi \,.\, \cos\phi$$

$$l_2 = \tfrac{1}{2}t \,.\, \sin\phi + k \,.\, \operatorname{cosec}\phi = \tfrac{1}{2}\pi \,.\, \cos\phi.$$

Considering the pinion, the centre of which is at O in both Figs. 1 and 2, the load-points CP_1 and CE_1 will be regarded as the most unfavourable from the point of view of "wear" and CP_2 and CE_2 from the point of view of strength. Both diagrams relate to spur gears.

Intensity of Loading, Spur Gears.—In both the cases described above the load is carried by one pair of teeth at the chosen load-points, and if the tangential load at the pitch circles per inch of face-width be denoted F_t lb, the normal tooth reaction per inch of length of contact line is

$$F_c = F_t \,.\, \sec\phi$$

where ϕ represents the pressure angle of engagement if different from that of generation.

Strength Factors

In comparing the bending stresses in given designs of tooth, it is possible to draw their outlines to any magnified scale and to proceed from first principles. It is more convenient, however, to draw all such outlines to a scale of 1 diametral pitch and to allow for the actual pitch by calculation.

Fig. 3 represents the tooth of a gear of 1 diametral pitch and 1in face-width generated by "rolling" graphically from a rack. On this diagram the chosen load-point for strength (CP_2 or CE_2) may be determined from the calculated value of l_2 and swung about the centre to give the point of application of the normal tooth reaction F_c. The line of action of this force inclined at an angle θ, intersects the radial centre-line of the tooth at A and with this point as the vertex an inscribed parabola may be drawn touching the fillet curves at B_1 and B_2.

From the angle θ and the scaled dimensions x and y, the components of stress at B_1 and B_2, by elementary theory, are

$$S_1 = \text{bending stress} = \pm(6F_c \,.\, x \,.\, \cos\theta)/y^2$$

$$S_2 = \text{direct stress} = (F_c \,.\, \sin\theta)/y$$

and the sum, according to whether it be compressive or tensile, is

$$S_b = \text{resultant stress} = F_c(6x \,.\, \cos\theta \pm y \,.\, \sin\theta)/y^2.$$

The "strength factor" is the ratio of tangential load to resultant stress for a tooth of defined form, which has a diametral pitch of 1, and 1in face-width, and it is denoted by Y, where $Y = F_t/S_b = (F_c.\sec\theta)S_b = (y^2.\cos\theta)/(6x.\cos\theta \pm y.\sin\theta)$. The use of a + sign in this expression gives a strength factor based on resultant compressive stress, and a − sign corresponds to resultant tensile stress.

The strength factors originally determined for 20 deg. spur gears, and incorporated in B.S. 436 : 1940, were based on load-points coinciding with the change-points (i.e., corresponding to what are here called precision gears) and on the resultant compressive stress. But it has been pointed out that gear teeth, when they break, nearly always fail by a fatigue crack which starts on the tensile side, viz., at B_2 in Fig. 3. Strength factors determined in the manner described for commercial gears on a basis of maximum tensile stress would therefore be more consistent with experience and with the tooth-form defined in the B.S. specification; the results are given in Fig. 4.

Two consequences may be noted: first, recalculated strength factors require a corresponding change in permissible stresses, since the actual strength of a tooth is not changed by a new method of calculation; and, secondly, the strength factor of a "commercial" tooth, determined as described above, is constant for a given addendum coefficient and is independent of the number of teeth in the mating gear.

In precision gears, however, the strength factor depends upon the number of teeth in the mating gear, and values can be charted or tabulated only in connection with a defined system of addendum modification. Fig. 5 gives strength factors for gears in which $k_p = k_w = 0{\cdot}5$.

In both commercial and precision gears the general expression relating nominal bending stress to tangential load, for gears of diametral pitch P and face-width f, is

$$F = (S_b \,.\, Y \,.\, f)/P$$

or

$$S_b = F \,.\, P/f \,.\, Y$$

Criteria of Surface Stress

The mechanism of surface failure, in any of its forms, is obscure and it does not yet appear possible to devise a method of determining permissible surface loading which will take into account all the factors involved—compressive and tangential forces, and the frictional, thermal and hydrodynamic effects of combined sliding and rolling. Pending a better understanding of these matters and their quantitative evaluation, use is made in practice of the only contributory quantity that can be calculated, namely, the direct compressive stress, or a function of it. It appears desirable to repeat that the comparison of surface loading in terms of load per inch of line contact is most misleading.

By the classical treatment, due to Hertz, of the compressive stress in perfectly elastic, isotropic materials under static line contact,

$$S_{max} = 0{\cdot}591 F_c^{\frac{1}{2}} \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{\frac{1}{2}} \left(\frac{1}{E_1} + \frac{1}{E_2}\right)^{-\frac{1}{2}}$$

where R_1 and R_2 are the radii of curvature, E_1 and E_2 the moduli of elasticity of the respective materials, and F_c the load per inch of line contact, units in pounds and inches. But experience does not support the facile assumption that a compressive stress calculated in this way is an adequate criterion of permissible loading under the conditions of gear engagement, if S_{max} is judged solely on the basis of the permissible compressive stress in a material under static loading. To cite only one example, the performance of bronze as a worm wheel material, in comparison with ferrous materials, sufficiently shows the importance of other properties, notably the coefficient of friction and thermal conductivity.

A simpler criterion, which gives latitude for the addition of empirical adjustments, is expressed by

$$S_c = F_c/R_r$$

where S_c is described as a "surface stress," F_c is as before, and R_r is the relative radius of curvature given by

$$R_r = R_1 \,.\, R_2/(R_1 + R_2).$$

A history is attached to the use of a surface stress criterion of this sort, which may be worth recording. At the time when surface

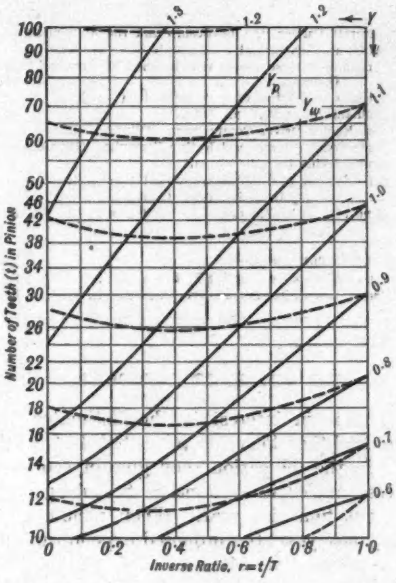

FIG. 5—*Chart of Strength Factors for "Precision" Spur Gears*

loading first came to be considered as a limiting factor, it was commonly held that the load-carrying capacity was proportional to $\sqrt{R_r}$. One rather naïve hypothesis leading to this conclusion was that the band of contact covered an area over which the oil film was less than 0·001in thick.

In 1930 or thereabouts, the author and his colleagues decided that this basis was inadequate and that the criterion $S_c = F_c/R_r$ was rational. They proceeded to apply it to industrial gear units. But the effect of changing the index of R_r from 0·5 to 1 is to increase the calculated capacity of large gears relative to small ones, and some of the larger gears designed on this basis were inclined to develop pitting a little prematurely. It was therefore concluded that perhaps the oil film had some influence in widening the band of contact in a manner favourable to the smaller gears, and some experiments on rolling sliding discs, carried out at about the same time, also suggested that the surface loading which produces pitting increased less rapidly than R_r. It was therefore decided to adopt a modified criterion represented by

$$S_c = F_c/R_r^{0{\cdot}8}.$$

Although this relation was purely empirical it has given satisfactory results over a period of about twenty years, and is the basis of current British Standard rating formulæ for wear. Some gear designers, however, use the simpler criterion $S_c = F_c/R_r$, and it is a disadvantage of the modified criterion that working stresses derived by the two methods are not comparable with each other. It will be shown later, under the heading "Speed Factors," that the index 0·8 can now be abandoned in favour of the simpler criterion, which alone will be used in the treatment that follows.

(To be continued)

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THE DEFENCE ESTIMATES

THE main interest in the Estimates for the Fighting Services presented last week lies in the indication they give of the progress made in rearmament during the current financial year. When announcing, early last year, the proposed expenditure on rearmament of £4700 million during the three years ending March, 1954, the late Government gave a general picture of what it was hoped to achieve. The Navy is to have a specified number of new fast anti-submarine frigates and minesweepers of modern design; ships under construction are to be modernised and completed, and modern equipment is to be provided for existing ships. The Army is to be built up to ten active and twelve reserve divisions at full strength, and modern equipment provided for these divisions and for the anti-aircraft command. The R.A.F. is to be equipped with aircraft of the latest types and to be greatly expanded, particularly the forces placed under the Supreme Allied Commander, Europe, though the front line strength aimed at was not revealed. In spite of unavoidable delays due to labour shortages and scarcity of materials—specially steel—progress on the whole may be regarded as satisfactory and there is no reason to be ashamed of the contribution this country is making to the defence of the free world.

By March 31st, £1131½ million will have been spent—almost £18 million more than the estimate for the current year; and during 1952–53 defence expenditure is expected to total £1462 million, or £1377 million, allowing for economic aid to be received from the United States. It is interesting to note that of this sum £12 million is included for "infrastructure," representing this country's share of the contribution required from all the N.A.T.O. countries for the construction and development of airfields, communications and headquarters for the common defence. Since the estimates were prepared, it has been stated that all three Services are to benefit from the recent agreement with the United States, which provides for a total of £85 million of economic aid to be allocated to defence expenditure. Allowing for this economic aid, naval expenditure is estimated at £332¼ million, an increase of £53¾ million on the current year. Progress in the initial stages of the naval rearmament programme has been concentrated on completing designs and placing orders, but the stage has now been reached when a considerable increase of manpower on naval work in the shipbuilding yards will be necessary to maintain progress. In spite of the schemes of upgrading and training which industry has been asked to develop, the manpower problem seems likely to become acute during the coming year. The Royal Dockyards are being used to the limit of the labour force available but, even so, part of the programme of modernisation and conversion as well as a proportion of repair and refit work must be carried out by private industry. Orders for some of the new minesweepers have had to be placed with firms not normally engaged in naval work. Nine new fast frigates and sixty-five coastal and inshore minesweepers are now under construction in addition to one large fleet carrier, five light fleet carriers and six destroyers which have been building since the war; and there are still fifteen more fast frigates and a large number of small craft to be built and forty-five of our existing 110 destroyers to be converted to fast frigates before the programme is complete. Finally, over and above naval rearmament, private yards already have orders for merchant ship building totalling some £600 million, which, in normal circumstances, would keep them fully employed for the next four or five years. In his statement accompanying the Estimates, the First Lord referred to the development of detection equipment against the snorting and submerged submarine. As it is no secret that radar can now detect the snort tube at an effective range, it is to be hoped that he is referring to the seeking out and detection—as opposed to the interception and detection by asdic—of the genuine submarine of the future, which will be driven by nuclear energy or by oxygen bearing fuels and will be capable of navigating for long periods entirely submerged, independent of the snort. While these types of submarines are still under investigation in this country, the United States Navy has a prototype of each now under construction. Other anti-submarine measures under development include more flexible and more accurate weapons of the ahead-thrown type and a homing torpedo which seeks out and destroys the target whatever evasive measures may be taken.

Army Estimates are up from £428 million in the current year to £491½ million (allowing for U.S. aid) in 1952–53. Tanks and vehicles account for 20 per cent of the entire production expenditure and several hundred "Centurion" tanks fitted with the latest armament are to be delivered during the coming financial year. This is welcome news, for the "Centurion" is one of the best tanks, if not the best, of its size in any modern army. The only mention of a more modern tank is the Secretary of State's reference to an expansion in our capacity for the large-scale production of modern tanks. Many thousands of combat and general service vehicles of the new post-war range are being produced and new weapons and equipment will begin to reach the troops in substantial quantities in the coming year. Great efforts have been made to modernise our anti-aircraft weapons—an expensive but essential expedient pending quantity production of guided missiles. Guided missiles are intended for use at ranges between those at which our fighter aircraft and anti-aircraft guns can operate and are without question the most promising weapon in the anti-aircraft armoury. The largest increase is shown in the Air Force Estimates, which go up to £437½ million (allowing for U.S. aid) compared with £330½ million for the current year. Figures showing the number of aircraft added during the current year are unfortunately not revealed, but it is at least satisfactory that nearly all our existing regular day interceptor squadrons now have the latest marks of "Meteor" aircraft; that the re-equipment of our night fighter squadrons with jet aircraft is almost complete; that the Royal Auxiliary Air Force squadrons have all been equipped with jet aircraft; and that the first "Canberra" squadrons have now been formed in Bomber Command. In his accompanying Memorandum the Secretary of State emphasises that while new squadrons have been added to our front line strength, the programme for the coming year provides for a much larger increase than in 1951–52, and also prepares for a still further expansion. Pending quantity production of the "Valiant" and later types, the medium bomber force which has been strengthened by additional squadrons of "Washingtons," will still be composed of "Lincolns" and "Washingtons." Coastal Command is being strengthened with new squadrons of "Shackletons" and also of "Neptunes" from the United States. Our largest expan-

sion, however, is earmarked for the Second Tactical Air Force, operating under the Supreme Allied Commander. Its front line strength is to include squadrons of "Venom" aircraft.

OCTANE NUMBER AND ENGINE KNOCK

CONTRARY to the beliefs and plans of the big petrol distributors, branded motor fuels will not be on sale this spring. That fact was revealed last week by Mr. Lloyd, Minister of Fuel and Power, who, in a written reply to Viscount Hinchingbrooke, declared that the Government had decided that in the present financial and economic position of this country premium brands of petrol could not yet be introduced. This decision must have come as a shock to the fuel producers who have built and are building new refineries capable of producing high-grade, 80 octane fuel, and will now have to confine costly plant to the presumably wasteful process of producing 70–72 octane pool spirit. For a given combustion chamber design, compression ratio has always been the main variable used by the designer of automobile engines to obtain maximum thermal efficiency, and the trend towards increased ratios is still apparent. It is well known that the onset of detonation or pinking limits the compression ratio to be adopted in an engine, and, further, that there are large differences between the knocking tendencies of the various hydrocarbons which are being used in fuel production. According to the now generally accepted theory, knock is associated with the self-ignition of the "end gas," i.e., the last part of the charge to burn. This self-ignition occurs under certain critical conditions of temperature and pressure, and is attributable to pre-flame reactions giving rise to a critical concentration of peroxides which "trigger" the ignition of the end gas. The significance of "knock" and its methods of measurement formed the subject of papers presented before the Institution of Mechanical Engineers on February 22nd.

The octane requirements of automobile engines are difficult to assess because they vary considerably with operating conditions. They depend, for instance, on engine temperatures, speed, load, spark advance, and mixture strength. They also depend on engine conditions. Combustion chamber deposits and the condition of valve seatings and sparking plugs all have some effect on octane requirements. Of all design features, however, combustion chamber design is known to have the most important influence on octane requirement and, consequently, on the permissible compression ratio. Investigations carried out in this country and in the U.S.A. on a great number of vehicle engines of different design have shown that side-valve engines have low octane requirements relative to their compression ratios. It has to be recognised, however, that difficulties may be experienced in the design and operation of such engines above about 7 : 1 compression ratio. It is doubtful, therefore, whether advantage can be taken at higher compression ratio of the desirable low requirements of this class of engine. By contrast overhead valve engines generally have high octane requirements, and all show a diminishing requirement with increasing speed. It may be surprising that the overhead valve engine requires a fuel of higher anti-knock value than the side valve engine, but this characteristic is undoubtedly a consequence of greater breathing capacity and higher mean effective pressure. For this reason alone, apart from other considerations, the overhead valve design is more suitable for use with high compression ratios, and there is no doubt that an increasing number of overhead valve engines will be manufactured as soon as the number of high octane fuels available rises. It must be remembered, however, that the returns to be obtained by raising the compression ratio tend to become less significant if the octane requirements of individual engines rise too sharply with increased ratios. The users would not thank the engine designers if future development led to an octane requirement which could only be met by the use of special and expensive fuels of limited availability!

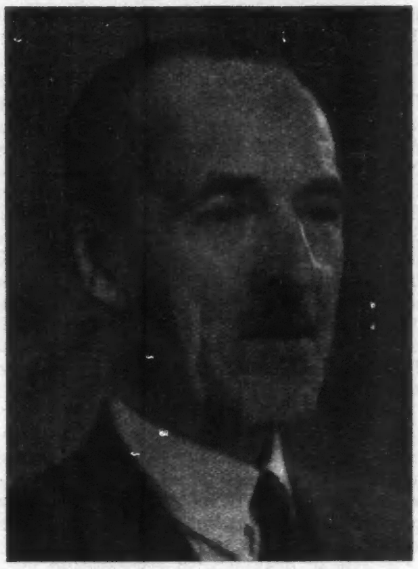
It is known that American motor manufacturers have endeavoured to anticipate many years' normal development by producing an experimental engine with a 12 : 1 compression ratio, but such a development must be considered premature, since even the Americans are not in a position to manufacture, at a reasonable price, the fuel required by such an engine. The cost of manufacturing high-grade petrol increases rapidly as the octane number is increased beyond 82, and it seems wasteful, from the standpoint of conserving the world's petrol resources, to develop engines necessitating highly synthetic fuels, which require the expenditure of energy, i.e., the consumption of part of the fuel, for their manufacture. It is questionable whether it is right to obtain high efficiency if, for this purpose, a comparatively expensive method is used in the manufacture of the fuel required, and it can be argued that, if compression ratios of 12 : 1 or higher are under consideration, the diesel engine, which uses fuel requiring a minimum of processing, is a sounder approach. Efforts should, perhaps, be devoted to overcoming some still existing basic difficulties, in particular those connected with injection equipment, rather than to developing very high compression ratio engines requiring expensive fuels. For the future development of automobile petrol engines it must be borne in mind that higher compression ratios are justified only if their use results in an overall saving to the consumer; gains in economy must more than offset increased fuel costs. Balanced development will require active co-operation between engine designers and the petroleum refiners with a continuing emphasis on knock elimination, not only by improvements in the fuel, but also by improvements in combustion chamber design. From the oil companies' point of view it would be more satisfactory to avoid an excessive increase in octane requirement than to spend a lot of money in providing fuels of high octane number which subsequently might be found unnecessary.

Obituary

P. C. POPE

ENGINEERS and fuel technologists will learn with deep regret of the death of Mr. P. C. Pope, which occurred, suddenly, in London, on Saturday last, March 1st. For many years he was the secretary of the Institute of Fuel, from which office he retired in February, 1946.

Philip Cosby Pope was born on January 26, 1872, and was educated at Tonbridge School. He served an apprenticeship with Richard Hornsby and Sons, of Grantham, and subsequently held appointments on the staffs of the former British Westinghouse Company and the Lancashire Power Company. Mr. Pope later became the Manchester representative of Siemens Brothers and Co., Ltd. The early part of his career was spent principally in the application of mechanical and electrical power in Lancashire collieries. During the first world war Mr. Pope joined the department of explosives supply, set up by the Ministry of Munitions, as purchasing director. Prior to that, however, he had become particularly interested in fuel problems, and in the years immediately following the first world war he resumed those activities, especially in connection with the low-temperature carbonisation of coal.



P. C. POPE

In 1925 Mr. Pope was chairman of the council of the Institution of Fuel Economy Engineers, and Sir William Larke occupied a similar office with the Institution of Fuel Technologists. The first Lord Melchett—then Sir Alfred Mond—was president of both institutions, and P. C. Pope was prominent among those who commended the merging of the two bodies into what in July, 1927, became the Institute of Fuel. In September of that year Mr. Pope was appointed secretary of the Institute, in which position he continued until February, 1946. During his long tenure of the secretaryship Mr. Pope's unbounded enthusiasm and energy were undoubtedly responsible for the rapid growth of the Institute of Fuel and the widening of its influence. Mr. Pope's outstanding service as secretary was acknowledged by a presentation of silver tokens which was made to him in 1943.

After Mr. Pope's retirement from the secretaryship in 1946 he continued for some time as adviser to the council, and, right to the end of his life, he maintained his active interest in and contact with the Institute's affairs. Another fitting acknowledgment of the esteem in which he was held and of the services that he had so conscientiously performed was made on Mr. Pope's retirement, when honorary membership of the Institute of Fuel was conferred upon him.

Literature

Refrigeration Principles and Practice. Edited by Dr. EZER GRIFFITHS. London: George Newnes, Ltd., Tower House, Southampton Street, W.C.2. Price 42s.

THOSE engaged in the profession of refrigerating engineering have for long had to deplore the absence of a comprehensive English work suitable either as a textbook for students or as a reference book. In recent years a number of American books have appeared, and they have provided the only useful source of information on the subject. It was therefore natural to entertain hopes that the present volume would prove to be the standard work so long awaited; for the books emanating from the U.S.A., admirable as several of them are, naturally do not give much information regarding British practice. These hopes are far from being completely fulfilled.

It is rather surprising that the title chosen for the present work should be almost identical with that of an American book, *Refrigerating Principles and Practices*, by Norman Sharpe; it is also remarkable that the contents and layout of the two books have little in common. The American work contains chapters on the calculation of refrigeration loads, the properties of refrigerating fluids, the principles of various refrigerating systems, and the design and construction of compressors, heat transfer equipment, and other components of refrigerating plant. Little space is, however, devoted to applications of refrigeration.

The general plan of the work under review is very different; it consists of some thirty chapters contributed by almost as many authors—many being no more than reprints, with or without condensation, of previously published papers or articles on specialised subjects related to refrigeration. The part of the book dealing with refrigerating machinery is disappointingly short. This is not meant to imply that the remainder must be of little interest to engineers, for the refrigerating engineer requires knowledge of very much more than the thermodynamics of refrigerants and the mechanical operation of plant, if he is to be able to engage in that co-operation with the user of refrigeration which is essential to the satisfaction of the latter. It appears, however, to be an unavoidable result of the plan of the book, not only that the merits of the various chapters must differ greatly, but also that the space devoted to the various subjects is not in all cases proportional to their importance.

A detailed consideration of each chapter is hardly called for, but certain points deserve to be mentioned. Chapter II, on Fundamental Knowledge Concerning Meat, is interesting and authoritative, but all too brief. Chapter III, on Cooling of Beef, provides interesting information, based on a publication of the Government of the Commonwealth of Australia regarding practice in that country. Chapter V, on Refrigerated Gas Storage of Apples and Pears, mainly by Dr. J. C. Fidler, is an extremely lucid and illuminating account of principles and practice in that field, and would be difficult to better in the space allotted to it. Chapter VII, on The Freezing of Food, contributed by the laboratories of J. Lyons and Co., Ltd., is somewhat sketchy; it contains a fair amount of useful information, but leaves many pertinent questions unanswered. Chapter VIII, based on a pamphlet of the Food Investigation Board, is an excellent brief summary of the subject of fish freezing. Some discrepancy between statements regarding the effects of slow and rapid freezing is to be noted as between this chapter and the previous one.

Chapter IX, on Laws Governing the Evaporation of Water and Sublimation of Ice, is interesting, but rather inconclusive; the close relation between rates of transfer of heat and of water vapour, so useful in the design of evaporative coolers and the like, is not clearly brought out. Chapter XI, on Thermal Insulation, by Dr. Ezer Griffiths, is authoritative and valuable. It contains a fairly extensive table of thermal conductivity data, from which, however, some omissions of importance are to be noted, including building stone of various kinds, silica aero-gel, and single and multiple glass panes. In Chapter XIII, on Refrigerator Equipment for Canteens and Shops, a short but good summary of the subject, the average weight of foodstuffs stored in a refrigerated cabinet is given as 3 lb per cubic foot (page 220). Possibly this is meant to be the daily input; the amount that can be stored at any time is two or two and a half times as great.

Chapters XIV and XV, on Refrigeration in Food Processing and the Manufacture of Ice Cream, respectively, contributed by the laboratories of J. Lyons and Co., Ltd., are disappointing. The very wide field implied in the titles is skimmed over with great rapidity, and such applications as brewery refrigeration, freeze-drying, and dough retarding receive only the briefest mention. Chapter XVIII, on Marine Refrigeration, by G. Mann, is, in general, an excellent description of conditions of transport, air circulation, &c., but has little about the refrigerating plant involved. A reference on page 280, in a paragraph dealing with cooler performance, to the symbol k_t as "coefficient of sensible heat transfer (non-dimensional)" may puzzle many engineers. It is, in fact, not what is usually referred to as coefficient of heat transfer at all, but the Stanton number (equal to the Nusselt number divided by the product of the Reynolds and Prandtl numbers), and has to be multiplied by the product of the velocity, density and specific heat of the fluid in order to give the heat transfer coefficient.

Turning to that section of the book dealing with refrigerating plant design, the most valuable chapter consists almost entirely of a condensation of the 1941 Hawksley Lecture by Lord Dudley Gordon on modern refrigerating circuits. Although refrigerating fluids are mentioned in the title of this chapter, no information on these is included. A number of useful references to sources of data are given, but the statement that "a good introduction to the subject will be found in *The Mechanical Production of Cold*, by Ewing," may be misleading. The book referred to, excellent pioneer work as it was, and still worth reading for its description of basic theory, is entirely outdated as a reference for refrigerant data. Chapter XXVI, on Air Conditioning Installations, comprises short descriptions of two plants, neither of which could be correctly described as an air conditioning installation, since neither includes provision for humidity control. Chapter XXVII, on The Heat Pump, is quite good, though brief. The use of the term coefficient of performance in connection with the heat pump, as in this chapter, is to be discouraged, since this term is already well established in refrigerating theory with a different connotation. No generally accepted name for the number of units of heat delivered by the condenser per unit absorbed in the form of power exists; would not advantage ratio meet the case? Chapter XXVIII deals with the charging and running of refrigerating plant. The basis of such an account should be a description of the criteria of correct charge and regulation as influenced by the kind of circuit and of refrigerant control, but these are by no means adequately covered in this chapter. The last and longest chapter in the book is devoted to a "survey of refrigerating equipment." This covers a wide field and consists of brief descriptions of the products of leading British manufacturers. Each chapter concludes with a useful bibliography.

To sum up, this book, despite its many merits, is not the comprehensive and authoritative work so long awaited, to which the user and the designer of refrigerating equipment may be able to turn in the confident expectation of finding guidance towards the solution of many of their problems. Meanwhile, however, it deserves a place in the library of everyone concerned with refrigeration.

Fundamentals of Automatic Control. By G. H. FARRINGTON. London: Chapman and Hall, Ltd., 37, Essex Street, W.C.2. Price 30s.

UNTIL recently there has been no textbook on the theory of control published in this country; not long ago the Cambridge University Press published Macmillan's "Introduction to the Theory of Control in Mechanical Engineering," and now we have the present volume by the consulting engineer to Ilford Ltd. Macmillan's approach was frankly mathematical and an expository text of fundamental principles; Mr. Farrington, on the other hand, has started on the assumption that his readers will be unaccustomed to mathematical methods and has introduced such methods step by step in an attempt to make them clear to the non-mathematically minded. This has had the effect of loading the text with mathematical expositions whose rigour would not satisfy a specialist, but which are still not easy to grasp, and has also led the author to give detailed working which is tedious to follow and leads to loss of the thread of the argument. It is improbable, on the other hand, that the tyro will thus acquire sufficient mathematics to follow the more advanced work.

Considerable use is made of argument by analogy with particular reference to electrical networks. Whereas this may make things clear to electrical engineers, others may find the analogies difficult to comprehend and a source of error. All such analogies turn on identity of mathematical expression, and it would appear that, except to specialists in electrical network analysis, it is better, and leads to less errors, to use the mathematical relationships directly without reference to "equivalent" electrical circuits unless the electrical analogue is to be used as an experimental method of solution of complicated relationships which is not the purpose here.

The publishers claim that this is a first-class textbook for students and experienced engineers. For both classes it would be considerably improved by assuming a rather higher level of mathematical knowledge and deleting the redundant expository matter. This would enable a more rigorous approach to be taken from the beginning; for example, the polar curve method of analysis can be clearly demonstrated from the basic equations as is done in Chapter IV; there is no need to beg the question in Chapter II by

arguing from Fig. 6, which is based on Fig. 4, which is in turn stated to be "the relationship in a typical case" of phase angle and amplitude with the frequency of a sinusoidal potential. All this must be very confusing to the student, although it will probably not trouble the experienced engineer who is familiar with the literature.

When Mr. Farrington leaves the basis and proceeds to the applications, his treatment is much happier; in particular, the chapter on Plant Analysis, although making much use of the network analogy, clearly applies the principles to a particular plant, and the chapters on the analysis of controlling units and control selection and adjustment give an excellent summary of the present state of the art. The author has a considerable contribution to make to the literature on automatic control, and it is unfortunate that this book has fallen between being a textbook for the student and a critical review of the field for the practician. It is hoped that Mr. Farrington will produce a drastically revised edition on the latter lines.

Letters to the Editor

(We do not hold ourselves responsible for the opinions of our correspondents)

ASSESSMENT OF LOCOMOTIVE PERFORMANCE

SIR,—May I first of all reply to Mr. Munnion that the L.N.E.R. "A 4" engine which sustained 87 m.p.h. on the level was No. 4498, "Sir Nigel Gresley," not one of those fitted with double chimneys.

Now with regard to the cut-off indicator, I would most heartily agree that it is often far from reliable as a means of assessment on ordinary runs, and definitely misleading at times when comparison is attempted between the performance of different types of locomotive. But the instances Dr. Tuplin quotes of high speed down the Stoke bank, with cut-offs stated as 35 per cent on one run, and 15 per cent on the other, were made in very different circumstances which can easily account for the disparity. Engine No. 4489, on a trial trip of June 30, 1937, was pressed to a very rapid acceleration, whereas No. 4491, on a service train, was allowed to develop her high speed with the ordinary working cut-off. The following table shows the difference:—

Distance, miles	Stations, &c.	Engine 4489 Load 325 tons		Engine 4491 Load 325 tons	
		Time	Average speed	Time	Average speed
		min. sec.	m.p.h.	min. sec.	m.p.h.
0·0	Stoke Box (pass)	0 00	—	0 00	—
3·0	Corby	2 18	78·3	2 26	74·0
7·9	Little Bytham	5 19	97·5	5 37	92·2
11·5	Essendine	7 19	108·0	7 42	103·4
15·3	Tallington	9 50	90·6	9 52	105·2
20·6	Werrington Junction	13 35	84·8	12 59	102·0
Maximum speed, m.p.h.		109		106	
Average speed, Bytham–Werrington, m.p.h.		92·4		103·5	

No. 4489 was blasted up to 109 m.p.h., on a long cut-off, for show purposes, and then eased down, while No. 4491 sustained her high speed till eased off in the approach to Peterborough.

When it comes to comparing different locomotives the cut-off is often quite useless as a means of assessment, as the valve design on one engine may allow for more steam to enter the cylinders for a particular cut-off than on another. During 1944 the L.M.S.R. ran some dynamometer car trials with engines of the "Converted Royal Scot" class, on which many diagrams were taken at very short cut-offs. At 15 per cent, full regulator, and a speed of 60 m.p.h., 1520 i.h.p. was recorded with engine No. 6138, while at 10 per cent cut-off, and 60 m.p.h., the i.h.p. was 1070. Then, in 1924, when "full dress" trials were conducted on the Great Western engine No. 4074, "Caldicot Castle," indicated horsepower figures varying between 1300 and 1350 were recorded at 65 m.p.h., working with full regulator and 22 per cent cut-off. But although considerably longer cut-offs were needed to produce less horsepower at roughly comparable speeds, no one is going to pretend that the "Converted Royal Scot" is a vastly more efficient engine than the "Castle." The results of the 1948 interchange trials showed that the overall performance of the "Scot" was in the usual 3·0 lb to 3·5 lb of coal per drawbar horsepower-hour range—the general average for a good British express passenger engine. In the 1924 trials the G.W.R. engine, using soft Welsh coal, gave an overall consumption as low as 2·83 lb per drawbar horsepower-hour, though the average performance on present-day coal would no doubt lie in the 3 lb to 3·5 lb range.

O. S. NOCK

Bath,
February 26th.

TREVITHICK'S FIRST LOCOMOTIVE

SIR,—Mystery has shrouded all the locomotives—only four or five—made by Trevithick in the earliest years of the nineteenth century. Any attempt to solve it is to be welcomed, and Mr. E. A. Forward's article in your issue of February 22nd will be read with great interest by all historians of the locomotive.

Mr. Forward's contention is that the precious old drawing of a "Tram Engine" in the Science Museum shows an engine built for a narrow-gauge line at Coalbrookdale, and not the famous Penydarran locomotive. If the dimensions—4½in diameter by 3ft stroke—in the drawing be correct, then it is certainly not the Welsh engine, which is known from a letter of Trevithick's to have had a cylinder of 8¼in diameter. In 1932, Mr. W. W. Mason presented a paper to the Newcomen Society (*Trans.*, Vol. XII), in the course of which he suggested that the drawing had been cut down and the original title removed. Mr. Forward, than whom no one was more familiar with the drawing, rejected this suggestion, but he added: "This drawing appeared to be a pricked copy from some other drawing by someone who had looked at the engine and had recorded it on paper." It is far from impossible that the same drawing served both engines, the written dimensions being appropriately altered.

Examining the drawing in the light of Mr. Forward's arguments, one is tempted to ask if it is a workable design? In the first place, there appears to be very little, if any, clearance between the outside of the boiler and the driving wheels. Now, the narrow-gauge railway at Coalbrookdale is assumed to have been laid with John Curr's angle-plate rails. These rails were of L section with very unequal legs laid on its side with the shorter leg projecting upwards, forming a flange for the guidance of the wheels. It is fairly certain that these flanges were inside the wheels and as the plate, on which the wheels ran, must have been 2in or 3in wide, there was no reason why the wheels of the engine should be pinched in, and every reason why they should not. Indeed, a not inconsiderable amount of side play between the wheels and the flanges would be desirable and even essential. In the discussion on Mr. Mason's paper, referred to above, Mr. Forward gave the width between the wheels as 3ft 1½in, which would ensure the necessary clearance. A more crucial point is the mounting of the wheels. The drawing seems to show that they were all independent, like wagon wheels, as Mr. Forward says. Now, as there was only one set of gearing, the wheels on one side of the engine only would be driven. The result would be a couple of 1ft 6in set up between the rail and the wagon couplings. When one thinks of the jolts and jars that would take place through the gearing it is natural to ask if the drawing is not seriously at fault. It would only have been necessary to raise the boiler by an inch or two to give space for through axles and a four-wheel drive.

Before turning to another point, may I say that the excessive coarseness of the pitch of the gearing which seems to surprise Mr. Forward is probably due to no more than a draughtsman's convention. Presumably the driving wheels were of wrought iron, for cast iron of such small section would have soon failed, but the spur wheels were no doubt cast and a coarse pitch would be necessary to give root strength to teeth only 1in wide.

Mr. Forward quotes Trevithick's letter of 1803 to Giddy, in which, referring to the Penydarran engine, he says: "The cylinder is 8¼in diameter, to go about 2½ m.p.h.; it is to have the same velocity of the piston-rod." If that means, as it seems to mean, that the piston speed is to equal the travelling speed, then the driving pinion would require to be approximately two-thirds the diameter of the driver; which it is not in the drawing—a point in Mr. Forward's favour.

The quotation from Randall's *History of Madeley* is intriguing. In it a Mr. Reynolds records that Trevithick had constructed working models, much resembling modern locomotives in construction, before the year 1800. Can Mr. Forward suggest what "modern" locomotives were in the author's mind? Randall's *History* was published in 1880; what was the date of Mr. Reynold's reminiscences? His statement that the boiler of the alleged Coalbrookdale engine was in use as a water tank at Lloyd's Crawston Pit, whilst the fire tubes were at Madeley Wood, is hard to accept. The boiler would not make a good tank with the flues removed and, as the flues were riveted in place, it seems unlikely that they were cut out.

There is one point about these early locomotives which seems to escape attention. Years later Stephenson had to make experiments to satisfy himself that natural adhesion between wheel and rail would suffice for the haulage of heavy trains. Trevithick seems to have known it in 1800, for all his engines had smooth tyres.

LOUGH. PENDRED

Twickenham, March 1st.

P.S.—The Loutherbourg romantic painting of Coalbrookdale is perfectly delightful. Was it the least bit like that?

SCIENTISTS AND TECHNOLOGISTS.—The number of scientists and technologists coming from the universities and technical colleges of Great Britain with ordinary first degree and higher degree qualifications (or their equivalent) in the academic year 1950–51 is estimated as being about one in 3000 of the population. This information was given recently in a written Parliamentary reply by Sir Arthur Salter, Minister of State for Economic Affairs.

Institution of Mechanical Engineers

GEAR TOOTH STRESSES AND RATING FORMULÆ

IT has long ceased to be the practice at the major engineering institutions for an author actually to read a paper at a meeting. Copies are circulated beforehand and the main object of the meeting is to discuss the paper. Authors, in "presenting" the paper, usually either summarise it or direct attention to particular parts of it. Sometimes, however, they offer a commentary on what the paper has to say—that is, in effect, they "discuss" their own paper, often with entertaining results. For who is likely to be better informed about the contents of a paper than its author himself? That is what Dr. H. E. Merritt did in "presenting" his paper on "Gear Tooth Stresses and Rating Formulæ" before the Institution of Mechanical Engineers last Friday, February 29th. On another page of this issue we reprint the paper. Below we print part of the author's introduction of the paper to the meeting.

When I started reading, writing and doing sums about gears, at what now seems to be a disconcertingly long time ago, it was all very simple. Rules for tooth proportions were innocent of elegant refinements such as addendum modification, whilst profile modification, although known to be necessary, was given a value visible to the naked eye at a distance of several feet. Rating formulæ were the original Lewis formula for strength, or variants of it, and surface loading was rarely taken seriously as a criterion of capacity.

But although the rules were simple, no two makers used the same ones, and nobody could prove that one set of rules was better than another. That, however, did not inhibit argument. In fact, gears have probably been the most prolific and continuous source of controversy in the whole field of engineering, and these controversies have sometimes reached a degree of acrimony normally achieved only by pure scientists.

One is reminded of an experience of Dr. Johnson's *Rasselas, Prince of Abyssinia*. In the original text (a quotation that I have used before, but it wears very well):

"Rasselas went often to an assembly of learned men, who met at stated times to unbend their minds and compare their opinions. Their manners were somewhat coarse, but their conversation was instructive, and their disputations acute, though sometimes too violent, and often continued until neither controvertist remembered upon what questions they began."

It is not the purpose of this paper to quench the fire of argument by a cold douche of facts. I am not in a position to do so, and will content myself with an *ex cathedra* statement, namely, that we cannot yet apply the "one-hoss-shay" technique to gear design; gears often wear out either too quickly for comfort or reputation, or too slowly for replacement business.

Nevertheless, we must have rules to work on, and an imperfect rule is better than none at all. Those that we now have are triumphs of guesswork, produced by masters of the art of drawing a mean line through a series of points resembling the pattern of an indifferent shot-gun. I have myself made a few contributions to the accumulated guesswork now enshrined in the British Standard Specifications for gears, together with an equal number of egregious errors, most of which have so far escaped detection. But guesswork can be made respectable by calling it a tentative hypothesis, and, as such, is commonly practised, and I will gloss over the errors by changing the subject or the argument.

One effect of the publication of B.S. gear standards has been to bring about greater uniformity in gear rating practice. It is questionable whether this has been, or will prove to be, a good thing. B.S. rating formulæ work well enough, in that the results are (as far as I know) generally satisfactory. But the actual margin of safety or durability is probably highly variable for different types, sizes or qualities of gears, and if this is so, some of the margins must be excessive. When different makers, working in different fields of gear transmission, develop their own formulæ and amend them as a result of experience, they probably approach closer to the truth, in patches. But when one set of formulæ, carrying the authority of the B.S.I., and exercising the hypnotic effect characteristic of all printed matter, come into general use, some initiative tends to disappear. Opportunities for cutting things a little finer here and there (which is the only way in which we can learn more about gears) may not be taken so frequently, and in a case like this a British Standard may in fact act as a deterrent or a handicap to the enterprising, particularly if the customer is a main contractor or an official who may be castigated for taking chances, but who will never be found out for wasting money on unnecessary safety.

It ought to be more generally recognised that rating formulæ have been continuously changing or continuously modified ever since they were invented, and the process will certainly continue. Some adjustment may be possible in limited fields, which might not be applicable in general, and any user of a rating formulæ ought to be able to ascertain, from the specification in which it appears, the methods or assumptions on which the constituent factors are based. He would then be in a better position to decide upon the directions in which some readjustment is likely to be well founded.

In short, it is unlikely that any one new and simple piece of knowledge will be forthcoming in the foreseeable future, which would command the confident acceptance by responsible engineers of a radical change in the structure of B.S. rating formulæ. The only reasonable approach seems to be to separate, to state and to examine the constituent parts of the formulæ, and to modify them one by one as experience and experiment may indicate.

Discussion

Professor W. A. Tuplin objected to the use in the paper of the term correction factor. Correction had been the term originally applied to the departure from a standard system that ought never to have been used in connection with gears, and the position was that departure from that arbitrary standard was desirable in almost every case; in other words, there had to be a correction of everything, so that the term "correction" had now lost its original meaning. In the British Standard it was called "addendum modification," which shaded it off just a little, but it still gave the impression that first one did the job and then one did it properly. Addendum modification was really a method of diameter determination. The system used in B.S.S. 436 was basically a pretty old one. As far as he could trace, it had originally come from America, but whether it had gone from this country to America first he did not know. It was just one system that anyone could devise, and it did not matter an awful lot what one did to a diameter modification, provided that the teeth were not sharp-pointed or undercutting. The fact was that the god of the involute was not a jealous god, and one could do what one liked within wide limits and "get away with it." The practical utility of the hardihood and flexibility of the involute system was that one could design gears for any centre distance whatever without departing from standard cutters. The first practical essential of a diameter selection system was that it should exploit this facility in a simple manner. B.S.S. 436 made no attempt to do so at all.

He would not dwell much on the subject of strength factors, because for the vast majority of gears one could always put the load capacity on strength well out of the way by adopting a sufficiently coarse pitch. That was not true for every class of gear, but it was in general, and in any case tooth failure by breakage was rather rare. The author mentioned that the strength factor was for a helical gear the same as that for spur gear teeth of the same number on the same diameter multiplied by the cosine cube of the spiral angle. Unless he had got it wrong, he thought that it was something less. He would say that the strength factor of the helical gear tooth was that of the spur gear tooth multiplied by a little more than $\cos \sigma$. The author mentioned that probable pitch errors would be small in comparison with deflection. That was true in some cases, but for most gears he did not think it was. The combined deflection of both teeth, if the load came to any reasonable chosen load point, was quite a small amount. If one took, for example, 0·5 per cent carbon steel gear, 10in diameter, running at 3000 r.p.m., the allowable load on the despised guess formula was about 660 lb per inch, so that the worst deflection was about $0{\cdot}17 \times 10^{-3}$, whereas the permissible pitch error for a thing of that sort was at least three times that amount and it might be six times. He thought that for soft steel gears, at any rate, the pitch error could be a lot more than the deflection. He felt that they were safe in saying that the tip relief in commercial unhardened gears was to accommodate errors and not deflection, which was small.

There were some irrational features of the load capacity formula in B.S.S. 436. First, it assumed that the dynamic load in any pair of gears at any speed was proportional to the basic allowable stress for the material. The dynamic load introduced by speed depended on the errors and elasticity of the gears which were determined by the moduli of elasticity and not by their strengths, so that it was fundamentally wrong to assume that the allowance for speed was proportional to the allowable stress. Secondly, it assumed that the dynamic load increased continuously with speed. An examination did not support that. The dynamic load, the load due to errors in speed, increased uniformly with speed for a time and then the rate began to taper off. The effect on dynamic load tended to be limited, and there was a limit beyond which the dynamic load did not increase with speed. Thirdly, it assumed that the size effect was applied by $\frac{1}{4}d^{-0.2}$ to the basic allowable load capacity instead of to the dynamic decrement. Fourthly, it assumed that the allowable stress for a given number

of applications varied with the number of applications per minute. The fact was that the number of applications of load required to cause failure of any given load was independent of the rate of application.

On the subject of the speed factor, he had seen some time ago some collected opinions from various people on the speed factor in gears. The opinions had been varied, but every one had expressed dissatisfaction. Every contributor had given the impression that, in studying this subject, he had run his head into a stone wall, or, at any rate, into a moderately thick brick wall; but through it all no one had appeared to suspect that the whole concept of the speed factor was fundamentally irrational. The number of applications of load per minute had no effect on the total number required to cause failure, and in gears the effect of rising speed was simply to increase the dynamic loads caused by pitch errors. That dynamic load must be subtracted from the load allowable at zero speed to determine what the permissible external load was at running speed. The speed effect was not a reflection of the basic allowable load, but a dynamic decrement. That depended on the elastic moduli and not on tensile strength, so that between soft steels and hard steels there was a very great difference in load capacity, but no difference in dynamic decrement. The dynamic loading could be assessed with the usual amount of guesswork, and the author was perhaps not quite correct in saying that it had not been crystallised into a form which could be embodied in rating formulæ for everyday use. He had himself given a paper on this subject some time ago, and in the discussion on the paper he had given a formula, which would be found in the Proceedings. It had been tried and it was generally better than the British Standard formula, where that formula fell down. He would say that the speed effect could not be rationally assessed by a speed factor at all. The effect of speed in any pair of gears on the useful load capacity was to subtract, a dynamic decrement and not a dynamic multiplier. The dynamic decrement itself did not depend essentially either on revolutions per minute or on feet per minute. It was determined by the magnitude of the error in pitch or profile and by the ratio of the time of introduction of that error to the periodic time of a natural vibration of the system formed by the masses and the elasticities of the gears. Because this dynamic decrement was thus determined by the combination of the two gears, the formula for it worked out more naturally in terms of the speed that was common to both—i.e., the pitch-circle speed—than it did to the rotational speed of either.

Mr. J. M. Newton, B.Sc., said that if one took an actual gear, designed to transmit 3000 h.p. from 5000 revolutions to 1000, with a pitch line speed of 220ft per second, and assumed that tooth to tooth error was as little as one-tenth of a thousand (he did not think any gears had reached that stage of accuracy yet), the dynamic load might reach eighty times gravity. The gears in which he was interested—helical gears for transmitting large powers—had heavy meshes, and accelerations of the order of 100 times gravity were right outside his experience. They were almost explosive in their violence. Therefore, he concluded that the flexibility of the tooth was important. This was not pure theory. Lloyd's had for some years been measuring the accelerations on marine gearing, and Drs. Dorey and Forsythe had read a paper on the subject some years ago before the North-East Coast Institution of Engineers. It seemed that in good gears the dynamic acceleration was seldom less than the useful load, and in bad gears it might be very much more. He had no doubt that the best stiffness of tooth was a function of the accuracy of manufacture, and he hoped that in the forthcoming British Standard for high-speed gearing for power transmission a more flexible standard would be introduced so as to deal with those dynamic forces.

Dr. D. G. Sopwith, M.Sc.Tech., Wh.Sc., said that the paper brought out clearly the complexity of the problem. One point which emerged very clearly was the need that there had been to solve the problem with very much less information available on the strength and material side than on the purely geometrical side. In solving problems of rating, permissible stresses, and so forth, the way which he thought was being followed in a number of cases was that use was being made of the great progress which there had been in theoretical and experimental stress analysis and in the knowledge of how materials reacted to those stresses; but he did not think it was then possible to say, "Oh, very well; we know our stresses now, we know what the material will do, and therefore such and such a stress calculated in this way will give the result we want." He thought that in the end they must decide on the basis of what had given satisfaction in practice. He did not mean that they could not progress; for what the procedure described showed was differences in the strength of what had, in using previous inaccurate methods of analysis, been taken to be parts of equal strength; it showed that some of them were actually stressed much more highly than others, and that the ratings of the ones which on the more accurate analysis had been conservatively stressed could be pushed up considerably. He thought that this was the basis underlying the work which the author had described. There was a very good field here for co-operation between experts in stress analysis, strength of materials, mechanisms and lubrication. There was a good deal of work on all those aspects in progress in various places, and just to take one of them—his own organisation, the Mechanical Engineering Research Laboratories—in addition to general work on fatigue, the work included the size effect, which had been referred to two or three times in the discussion; the measurement and the reduction of pitch errors; the measurement of tooth deflection under actual running conditions, which, as Professor Tuplin had said, was very important in deciding the dynamic stresses; the determination of those dynamic stresses by photo-elastic methods on gears actually rotating (this work being done extra-departmentally at Cambridge), and the investigation of pitting and scuffing failures in gears, and fatigue under contact stresses.

Mr. D. B. Welbourn, M.A., thought it would be of considerable interest if the author could extend the paper slightly to compare the formulæ which he was now proposing with those which were used in other countries, such as the U.S.A. and Germany, where large quantities of standard gears were also sold to standards of reliability comparable with those of this country at competitive prices.

Mr. S. Archer, M.Sc., A.M.I.Mech.E., not being a gear designer, but only a poor marine engineer who had, perforce, to check the gear designs against British Standard Specification 436, thought it rather like straining at a gnat and swallowing a camel to have to go through the considerable number of operations and interpolations from the various charts in that specification. Many of them were founded, as the author had shown, on complicated premises and geometric theories, only to finish up by having to multiply the results—two for pinions and two for wheels—by stress factors S_c and S_p, for the methods could hardly be claimed to be known to a sufficient degree of accuracy to warrant the considerable effort required to evaluate the other factors. He wished to make a plea for some attempt at still further simplification of the procedure for computation, at least until a good deal more was known about the missing links.

Dr. R. B. Heywood, M.I.Mech.E., summarised his remarks by putting the following question to the author: could they not bring the procedure for assessing the bending strength of gear teeth more into line with that generally adopted for determining the fatigue strength of parts, namely, from an assessment of the peak stress in the gear fillet?

Mr. A. M. Gunner stressed that it was urgently to be desired that a common standard should be evolved between this country and the U.S.A. in the first instance, and possibly on an international basis at a later stage in relation to the notation and symbols used for gear calculations.

Mr. W. Grant remarked that they were told that high-speed gears should be carefully lubricated and sometimes jet lubricated, but the stress factors quoted in the British Standard took lubrication into account not one iota. He did not know whether it was possible that the accumulated experience of many users could arrive at a surface stress factor or basic surface stress for any given material which would take the expected lubrication into account. It was not always possible to have the lubrication that was recommended; sometimes it was necessary to take what one could get, and it would be very useful if some compensating factor could be introduced to the basic stress factor given in the Standard.

Dr. H. E. Merritt made a short reply and the meeting ended.

Technical Reports

The Electrical Breakdown of Gases at 2800 Megacycles per Second (Report Ref. L/T214). By W. A. Prowse and W. Jasinski. The British Electrical and Allied Industries Research Association. Price 18s., postage 4d.—The report examines the onset and rate of progress of breakdown of gases under ultra high-frequency conditions in resonators. Streamer photographs and oscillographic observations are described for a number of gases. Theoretical considerations suggest that the mechanism initiating breakdown is step-wise ionisation, utilising energy resulting from previous inelastic collisions. A series of experiments, in which photo-ionisation was employed to initiate breakdown, is described.

A Single-Frequency Instrument for the Measurement of Interference with Television Reception Due to Ignition Systems (Report Ref. M/T102). The British Electrical and Allied Industries Research Association. Price 3s., postage 3d.—This report describes means by which a simple and readily producible instrument can be employed for assessing the interference with television reception caused by motor vehicle ignition systems. As a result, recommendations have been made to the B.S.I. for incorporation in the appropriate Code of Practice (C.P.1001 : 1947), and suitable equipment has been commercially developed.

The Effect of Water in Transformers (Report Ref. Q/T126). By M. R. Dickson, B.Sc. (Eng.). The British Electrical and Allied Industries Research Association. Price 9s., postage 3d.—The presence of water in an oil-immersed transformer is generally, and rightly, regarded with disfavour. It is not, however, right to suppose that a transformer necessarily gives any trouble when even quite large quantities of water are present. It is hoped that the present brief report will help to clarify this apparent anomaly and put the formation and effects of water in transformers in correct perspective.

Gas-Engine-Driven Compressors

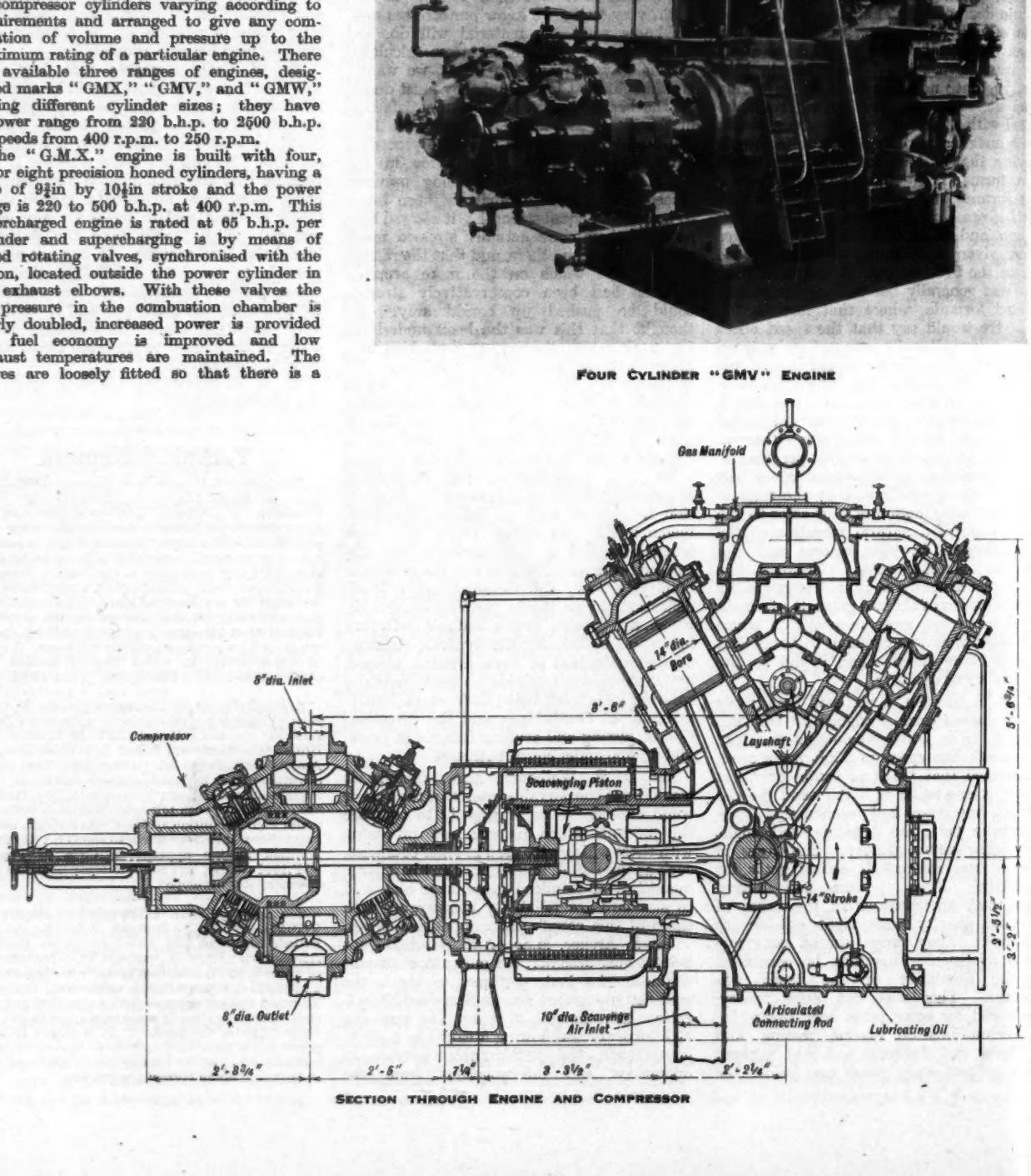
POST-WAR monetary difficulties and the need to curtail dollar expenditure by many countries made it almost impossible for the Cooper-Bessemer Corporation of Mount Vernon, Ohio, U.S.A., to export its products to the sterling area. As a result of this position it was decided that, as no equivalent British products were available, Harland and Wolff, Ltd., should undertake to manufacture, under licence, gas engines, gas-engine-driven compressors and other compressor units of Cooper-Bessemer design. The products of the American company have been in use in the oil fields and oil refineries for many years and from the experience gained in this industry a range of engines has been evolved to combine long life and low maintenance costs with economy in floor space.

The gas-engine-driven compressor sets consist of a 60 degree vee gas engine and a horizontal compressor built into one compact unit. The engines are of high compression, two-cycle design and are built in units of four, six, eight and ten cylinders, with the number of compressor cylinders varying according to requirements and arranged to give any combination of volume and pressure up to the maximum rating of a particular engine. There are available three ranges of engines, designated marks "GMX," "GMV," and "GMW," having different cylinder sizes; they have a power range from 220 b.h.p. to 2500 b.h.p. at speeds from 400 r.p.m. to 250 r.p.m.

The "G.M.X." engine is built with four, six or eight precision honed cylinders, having a bore of 9¾in by 10½in stroke and the power range is 220 to 500 b.h.p. at 400 r.p.m. This supercharged engine is rated at 65 b.h.p. per cylinder and supercharging is by means of timed rotating valves, synchronised with the piston, located outside the power cylinder in the exhaust elbows. With these valves the air pressure in the combustion chamber is nearly doubled, increased power is provided and fuel economy is improved and low exhaust temperatures are maintained. The valves are loosely fitted so that there is a minimum of friction between the valve and its housing, which is water cooled. Four compression rings and three oil control rings are fitted to the special cast iron pistons, which are oil cooled by lubricating oil supplied through drillings in the connecting rods. A continuous flow of oil passes through the chamber below the piston crown and is then returned to the sump and passed through an oil cooler. In addition to the advantages inherent with lower piston temperatures the danger of pre-ignition is eliminated.

Covering the intermediate range of horsepowers, namely, 440 b.h.p. to 1250 b.h.p., is the water-cooled "G.M.V." engine, which is available as a four, six, eight or ten-cylinder unit, the cylinders having a bore and stroke of 14in and each developing 110 b.h.p. at normal rating and 125 b.h.p. when supercharged. All the engines are designed to run at 300 r.p.m. Our photograph illustrates a four-cylinder unit and our line drawing gives a sectional view. There are two engine cylinders for each crank throw, which is also available for ac compressor. One of the characteristics of the engine is the use of the articulated connecting rod, which permits exact alignment of each compressor cylinder with a pair of engine cylinders and, in this way, the connecting rods are all in one plane and share a common crank-pin bearing.

FOUR CYLINDER "GMV" ENGINE



SECTION THROUGH ENGINE AND COMPRESSOR

In this engine an adequate supply of scavenging air is provided by a single-acting scavenge piston, for each crankthrow, which is attached to the compressor unit crosshead so obviating the need of a separate scavenge cylinder. The scavenging pistons discharge the air into a common receiver, cast integrally with the base of the engine. To minimise pressure drop, the scavenging air ports in the cylinders are constructed as venturi passages, which are positioned to give a predetermined direction of flow. It is claimed that this system enables a reduced air pressure to be used and a smaller amount of engine power to be absorbed. Another point made is that, due to positive scavenging, plus the design of exhaust manifold adopted, the engine is not critical to lengths of exhaust pipe.

The base, to which the engine cylinders and compressor assemblies are attached, is of special cast iron of a quality which permits of thin sections without affecting rigidity and strength. The main bearings are precision bored in the base, which is faced on the top and side to receive the engine cylinders and crosshead guides. Part of the casting forms the oil sump and the bottom of the base is designed to ensure a firm bond with the foundation, while longitudinal ribs make for tightness of the grouting. Large cover plates are provided and give easy access to all bearings and working parts within the base.

The cylinder head is of symmetrical uniform-stress design and incorporates a cylinder load balancing valve, a sparking plug with safety housing, a gas valve ignition coil and an air-starting valve. Precision bored cast iron cylinders are fitted and symmetrical hollow crown oil-cooled pistons which have four compression rings and two oil control rings. These pistons control the opening and closing of both air inlet and exhaust ports except in the supercharged engine when the exhaust is controlled by butterfly valves in the exhaust port elbows.

Extreme simplicity characterises the fuel injection system and the gas is supplied through a manifold located within the vee between the cylinder banks, the quantity of gas being controlled by a valve operated by a governor, which varies the supply with the engine load. Cams on the crankshaft, which runs in interchangeable bearings, operate push rods and rocker arms, which in turn actuate the fuel injection valves which are arranged to admit fuel almost simultaneously with the close of the scavenging period. The injection valves are of ported design, which directs the fuel towards the sparking plugs and into the streamlined flow of combustion air so that a good mixture is obtained, thus permitting regular firing at low loads. Fuels ranging from manufactured gas to the high hydrocarbon gases may be used with the minimum of adjustment and each injector can be adjusted to ensure that the cylinders are balanced.

Either low tension magnetos or battery ignition systems are available. With the former system two magnetos, one for each bank of cylinders, are mounted at the auxiliary drive end of the engine and are gear driven from the layshaft. Impulse couplings built into the magnetos intensify ignition for quick starting, and incorporated in the flywheel is an over-speed safety device which earths the magnetos or breaks the battery circuit by operating a switch.

The layshaft, which is located between the cylinder banks, is chain-driven from the flywheel end of the crankshaft and, in addition to the magnetos, drives, by either gear or chain, the air distributor, governor and cylinder lubricators.

A wide range of compressor cylinders, designed for low, medium and high pressures, are available, and the design of many of the cylinders incorporates a built-in by-pass valve, which obviates the use of outside piping. For the low and medium pressure bodies a special cast iron, having good wear resistant and lubricating qualities, is used, while the high pressure bodies are of cast or forged steel. The liners for all compressor cylinders are of special cast iron. The suction and discharge valves for the cylinders, which are interchangeable and of the standard self-cleaning ring-plate pattern, are ordinarily made of special cast iron. This material is also used for the removable valve seats, but for extremely high pressures the seats are of a high strength alloy. Compressor unloading is accomplished by lifting the suction valves or by opening the clearance pockets, and the operation may be carried out automatically or by a manual-pneumatic control using three-way air switches. Generally, five-step unloading is utilised but this number may be increased, depending upon the number of compressor cylinders per stage.

The third series of compressors, "Mark G.M.W.," are designed to deal with the larger outputs and the engines have cylinders of 18in bore by 20in stroke, each developing 250 b.h.p. at 250 r.p.m.

An Electro-Mechanical Cutting Method

FULL details have now been released of "Method X," an interesting cutting method which was developed to facilitate the performance of machining operations on any electrically conductive material, regardless of its hardness. The process was developed by the Method X Company, which is affiliated with the Firth Sterling Steel and Carbide Corporation, of Pittsburgh, Pennsylvania, and involves the shaping of metallic parts by an electric spark discharge of controlled intensity and duration. This method is not to be confused with other recent American developments for the machining of hard metals, such as the use of the arc effect to remove metal by thermal action, or the vibration of tools at a supersonic frequency in a liquid suspension of abrasives. Both of these methods have certain disadvantages which are claimed to have been overcome in the electro-mechanical principle incorporated in the "Method X" machine.

The machining action of this machine

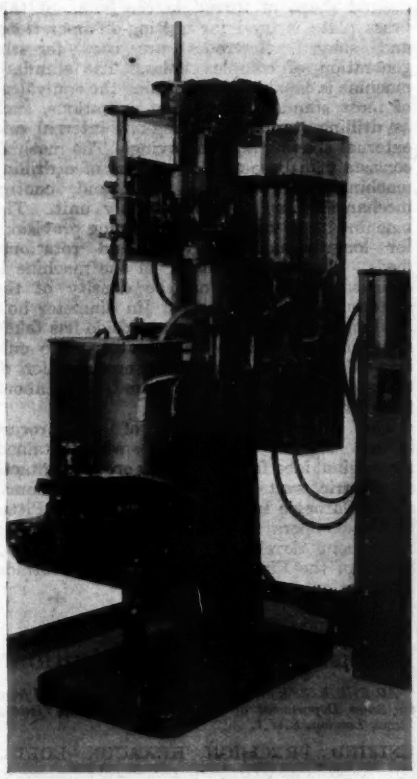


FIG. 1—"METHOD X" CUTTING MACHINE AND CONTROL CABINET

depends on a mechanical rather than thermal effect of electricity which sets up internal mechanical stresses by the use of extremely high current densities and thus causes the metal particles to detach themselves from the work material without resort to melting. Consequently, the exposed surfaces remain unchanged and it is claimed that surface finishes of 26 micro-inches R.M.S. can be obtained. It has been found that subsequent lapping of less than 0·001in will produce qualities of finish down to 0·15 micro-inch on sintered carbide. According to the makers of the machine, the centre-to-centre spacing of holes through the same workpiece can be controlled to approximately 0·0005in, and the fillet radii of blind holes can be made as small as 0·002in.

The Machine

The machine and its control cabinet are illustrated in Fig. 1, and Fig. 2 shows a view of the cutting head with the electrode cutting a shaped hole in a creep rupture test holder made of "S–816" alloy. The operation of the machine is almost completely automatic, requiring only that the work and electrode be inserted, the controls set and the starter switch thrown. The machine will then work without any further attention. The electrode movement is automatically controlled by an "Amplidyne" circuit. Power supply is obtained from a 220V, 60 c/s, single-phase line. The peak demand under the most severe cutting conditions is 7kW, and the spark discharge time is from three to five millionths of a second. Cutting is performed under a dielectric fluid which may be fuel oil, kerosene, or a special compound. Kerosene is being used now because its low specific gravity has been found to aid the process. A special fluid is being developed, however, which promises to double the cutting rate. The fluid is not contaminated in any way by the metal particles, and only needs to be replenished to make up for the amount lost by evaporation and work carry out.

The alternating current obtained from the supply is rectified and is applied to the negative electrode and the positive workpiece. The current builds up in the circuit to a value as high as 200,000A before discharge occurs across the dielectric fluid. The high current density of

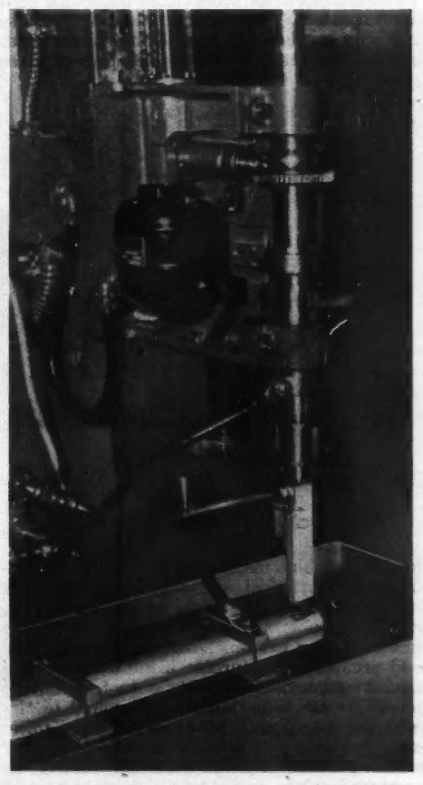


FIG. 2—CUTTING HEAD, ELECTRODE AND WORKPIECE

the discharge ionises the atoms surrounding the point where the arc strikes by knocking out valence electrons from their outer ring. The positively charged ions are then expelled by the surrounding positive body and simultaneously attracted by the negative electrode. The electrode is eroded, too, at a rate that is as fast if not faster than that of the work. One reason advanced for this is a chipping action which is due to the positive ions striking the electrode. The particles of both the electrode and the workpiece are removed as a fine powder, their size being a function of the current density and the cycle frequency. The powder, with the aid of baffles, settles down

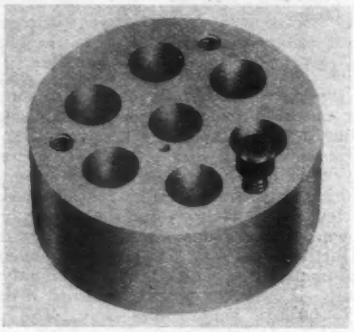


FIG. 3—SINTERED CARBIDE COMPACTING DIE

through the fluid to a sump. In theory, with a 50 per cent duty cycle, it is possible to achieve a rate of metal removal of 50 lb per minute.

The phenomenon which causes this particle detachment is not basically new, having been proposed in 1919 as a method of producing a colloidal metal. However, the conditions described at that time would not have resulted in sufficient metal removal to make the process commercially feasible as a machining method. Furthermore, Russian scientists have also described the phenomenon and have constructed an introductory machine to utilise it.

In the past, the fabrication difficulties encountered in connection with sintered carbides, with the so-called super-alloys, such as "S-816" and "Vitalium," and with hardened steels have restricted their uses to a certain extent. Now, the "Method X" process not only can be used to machine conventional shapes, but actually extends the uses of these

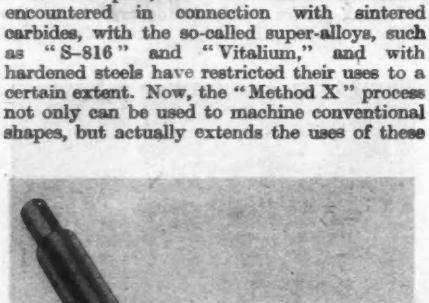


FIG. 4—GEAR COMPACTING DIE AND ELECTRODE

hard-to-machine metals and alloys by facilitating the economical and rapid production of complex geometric shapes, which, frequently, cannot be obtained by any other machining method. For example, the most satisfactory and promising gas turbine blade materials are almost unmachinable. Blade root mounting serrations are being laboriously ground to the intricate shapes and the extremely close tolerances required. Blade sections are shaped by either contour milling, precision casting or hammer forging—processes which are relatively slow and expensive. Die sections of sintered carbides are generally fastened by means of threaded steel sections brazed into the carbide and secured to the backing blocks by screws. Another means of fastening die sections is to shape, drill and tap wedges to fix the carbide die sections to backing blocks. Both these methods are slow and costly, and not entirely satisfactory, since both leave the mountings subject to loosening due to shocks encountered in service. The new method can be applied to all of these problems. Gas turbine blade contours and root serrations have been readily shaped, and sintered carbide die sections have been bored and tapped so that direct fastening to the backing blocks with machine screws could be accomplished. Fig. 3 shows a solid tungsten carbide compacting die section having an overall diameter of 5in and having three threaded holes for ¼in diameter screws which were machined entirely after the final sintering of the carbide. A sintered carbide gear compacting die with its generating electrode are shown in Fig. 4.

The electrodes used in conjunction with the machine are made of a highly conductive, easily machined material, such as brass. They are usually machined to a negative of the shape to be produced, provided the machining operation can be performed with the head moving in a vertical direction. When drilling and tapping through holes, a hollow electrode is used, which leaves a slug that can be salvaged. The electrode used for tapping is similar to a tap, i.e., its whole length is threaded. This is necessary because a single-point chasing tool would soon erode and have to be changed. Also, the threads on the tap have to be more pointed than usual in order to produce the desired shape of thread in the hole. A thin brass plate is used for cutting-off operations, and shaped electrodes are used for the generation of complex holes. The standard machine is capable of performing the equivalent of most standard machining operations, such as drilling, tapping, cutting-off, internal and external shaping and engraving. The machine consists of a base similar to that of a drilling machine, an electrode feed and control mechanism, and a power supply unit. The machine has a work table containing provisions for longitudinal, transverse and rotational feeds. The rate of cutting of the machine is believed to depend on the density of the material. The drilling of a ¼in diameter hole 1in long in sintered tungsten carbide has taken approximately thirty-five minutes. The cutting-off time for a 1in by 2in cross section of tungsten carbide has been found to be about forty-five minutes.

The initial development of the process is due to E. E. Teubner, who obtained the original idea from observing eroded contacts of electric switches. Dr. E. M. Williams, of the Carnegie Institute of Technology, Pittsburgh, co-operated with Mr. Teubner in the subsequent development of the machine on behalf of the Firth Sterling Steel and Carbide Corporation.

British Standards Institution

All British Standard Specifications can be obtained from the Sales Department of the Institution at 24, Victoria Street, London, S.W.1.

UNIFIED PRECISION HEXAGON BOLTS, SCREWS, NUTS (UNC AND UNF THREADS) AND PLAIN WASHERS—NORMAL SERIES. UNIFIED BLACK HEXAGON BOLTS, SCREWS AND NUTS AND PLAIN WASHERS—HEAVY SERIES

Nos. 1768 : 1951 and 1769 : 1951. The publication of these two standards for Unified hexagon bolts, screws and nuts marks the most important development to date in the work of standardisation between the three North Atlantic Treaty countries since the signing of the 1948 "Declaration of Accord." It will now make possible really effective implementation of the agreement to adopt the Unified screw thread, the standard for which was published as B.S. 1580 in 1949.

At an important conference between industrial and Service delegates from the United Kingdom, Canada and the United States, held under the ægis of the British Standards Institution, agreement was reached in principle on the basic dimensions of hexagon bolts, screws and nuts, and overall limits were established for two series, Normal and Heavy series, based essentially on a selection from existing American standards. Apart from the military significance of this development, it will lead to interchangeability of many products in a wide range of engineering industries. In particular, unofficial announcements from the motor industry on both sides of the Atlantic indicate that they intend to adopt the Unified standard for their civilian as well as their armament production.

No. 1768 relates to the Normal series of Unified precision hexagon bolts, screws and nuts having Unified screw threads in a range of nominal sizes from ¼in to 1in inclusive. The tolerances prescribed are those appropriate to engineering work where a good standard of dimensional accuracy and performance is necessary. Dimensions and general requirements are given for hexagon bolts and screws and ordinary nuts, lock nuts, slotted nuts and thick slotted nuts. Dimensions of plain washers are also included. Formulæ for the calculation of dimensions for bolt and screw heads and nuts in intermediate sizes and sizes larger than 1in are given in an appendix, and among other information given are items relating to the mechanical properties of finished steel hexagon head precision bolts and screws and hexagon nuts and to the standard sizes of bolts which are most likely to be stocked by manufacturers when the standard comes into general use.

No. 1769 relates to the Heavy series of Unified hexagon bolts, screws and nuts in a range of nominal sizes from ½in to 2in inclusive. The hexagon sizes in this series are larger in proportion to the nominal diameter of thread than those in the Normal series, and it is hoped that this standard may go far to meet the needs of those who have felt the lack of the large Whitworth hexagon, the standards for which were withdrawn some years ago. Dimensions and general requirements are given for bolts, screws, ordinary nuts, lock nuts and slotted nuts, and dimensions of plain washers are also included. The tolerances are somewhat wider than those for the normal series, but it is recognised that bolts and nuts of the Heavy dimensions may be required with a higher grade of finish for certain applications. Requirements are accordingly included in respect of bolts faced under the head and machined on the shank and machined nuts. Formulæ for the calculation of dimensions for bolt and screw heads and nuts in intermediate sizes and sizes larger than 2in are given in an appendix. Prices 3s. and 2s. 6d. each respectively.

GEARS FOR INSTRUMENTS AND CLOCKWORK MECHANISMS : PART 1 INVOLUTE, SPUR, HELICAL AND CROSSED HELICAL GEARS

No. 978 : Part 1 : 1952. In revising this standard, which was first published in 1941 as a war emergency standard to assist in the reduction of types and sizes of gears used for instruments and the cutters for producing those gears, it was decided to produce the new issue in four parts.

The present publication applies to machine-cut involute, spur, helical and crossed helical gears of 20 to 200 D.P. for instrument and clockwork mechanisms. It provides for two classes of gears, Class "A" for use where a high degree of accuracy is required, and Class "B" for all other applications. It differs from the 1941 edition so far as the basic rack is concerned by the reduction of the radius at the tip in order to increase the tolerance allowable in the depth of engagement. In addition, the dedendum has been reduced and the radius of the clearance space has been increased in order to avoid excessive undercutting. Two basic racks are shown. One is intended for use where minimum backlash is required and the other for use where backlash allowance is needed.

Provisions are included relating to the modification to the addendum of pinions with sixteen teeth and less, and the extension of centre distance in spur gear pairs in which the sum of the number of teeth is thirty-three and less. This clause is supplemented by two appendices giving notes on addendum and centre distance, and on contact ratio with recommended minimum depths of engagement. The standard recommends that all spur gears should have involute form with the exception of those in weight-driven or spring-driven mechanisms in which the pinion is the driving member when the cycloidal may be preferred, and it recommends the use of diametral pitch for the expression of standard pitches.

The remaining parts of this standard, which are in course of preparation, and which are likely to be issued at an early date, are : Part 2, "Cycloidal Type Spur Gears," and Part 3, "Bevel Gears"; Part 4, "Worm Gears," has not yet been started, but will be undertaken when the revision of B.S. 721, "Worm Gears," has been completed. Price 2s. 6d. post free.

Articulated Diesel-Mechanical Railcars for Venezuela

The first of eight sets of twin-unit articulated diesel mechanical railcars being built in this country for the Venezuelan State Railways have now been delivered in South America. Each car of a unit has an under-floor engine of 130 h.p. with mechanical transmission to the end bogie. The control cabinet in the driver's cabin at each end of a twin-car set is built up of a number of individual units and completely wired and tested before installation.

IN addition to the wide range of railway gang trolleys and inspection cars it makes, D. Wickham and Co., Ltd., of Ware, Herts, has long specialised in the design and construction of railcars and coaches of various types for countries overseas. In the course of a recent visit to the firm's works we were shown under construction part of an order for eight sets of twin-unit articulated diesel-mechanical railcars for the Venezuelan State Railways. The first of these sets has been delivered and is at present undergoing acceptance trials on the Gran F.C. de Venezuela.

The railcars are intended for service on the 179km long, 3ft 6in gauge line between Caracas and Valencia, which includes a number of curves and gradients up to 2–4 per cent, and reaches an altitude of 1226m above sea level. Line conditions are such that a high maximum speed is less important for these units than good acceleration to maintain a reasonably high average overall speed, combined with good braking.

It will be seen from the general layout drawing which we reproduce that the two cars forming the articulated unit are practically of identical design. A driving cab is situated at each end of the unit and by mounting the power plant beneath the floors, the maximum space has been provided for passenger accommodation. In one car seats are provided for thirty passengers and in the other there are seats for twenty-seven passengers.

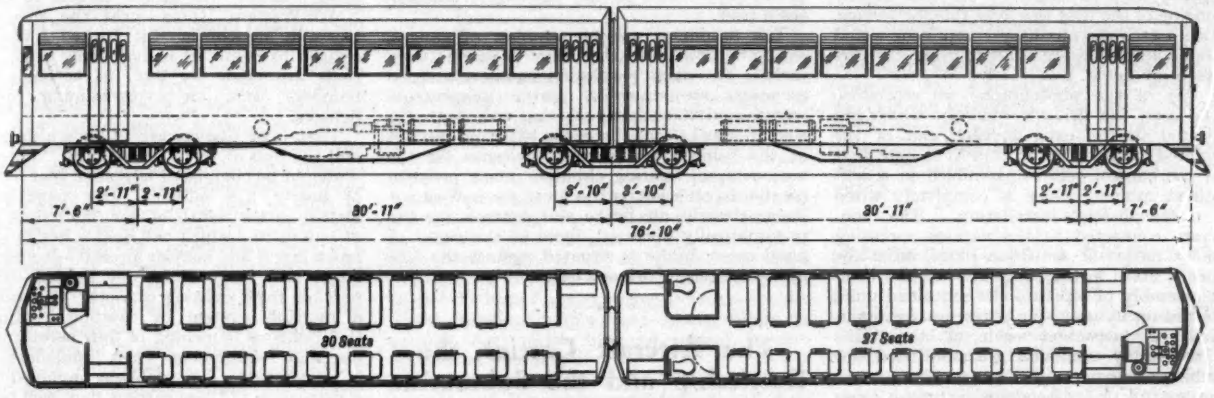
Following the maker's general practice for this form of railway coach, the use of a conventional underframe is eliminated by the construction of car bodies of stressed design in the form of a substantial box girder. Each body is built up by electric welding from square-section solid drawn steel tubing. In the method of construction which has been developed all members for a body are set in position and tack welded before any main welding runs are made. The assembly is then finish welded in a large manipulator designed to facilitate downhand welding throughout. Before the main body structure has its interior and exterior panelling applied, it undergoes deflection testing in a special rig using calibrated springs and screw jacks to apply the loads. Aluminium sheet of 16 gauge is used for all panelling, that for the outside being corrugated longitudinally, and that on the inside being covered with "Rexine." A gap of 2½in between the panels of the sides and roof is filled with heat insulating material, and all panels are attached by "Pop" riveting. By using this type of rivet the removal and replacement of any panels damaged in service is made a relatively quick and easy matter.

Each coach has a substantial flooring of tongued and grooved boards with an overlay of composition boards covered with heavy linoleum. Free access is given to the engine and transmission gear through large trap doors in the floors. Light alloy tubular luggage racks are fitted along the full length of each side of the cars and there is a space for a limited amount of luggage in each of the driver's cabs. The reversible seats are well spaced for passenger comfort and upholstered with spring boxes covered with rattan and edged with leather. Wide lift-up windows along the sides of the cars have double ventilating louvres fitted over their tops.

Supported on flexible mountings beneath the body of each car is a Leyland 130 h.p. oil engine set, to give an output of 100 b.h.p. Each engine is fitted with a "Freeborn" disc and ring coupling and has attached, through a bell housing, a Wilson four-speed, air-operated gearbox. From the rear of this gearbox the drive is transmitted to the inside axle on the end bogie by a Hardy-Spicer cardan shaft fitted with needle bearing universal joints. Mounted on the driven axle is a bevel reverse double-reduction gearbox of the firm's own design. In this box the usual two-bevel arrangement is used in conjunction with a sliding dog clutch change, to change from one direction of drive to the other. This dog is in the form of a gear, which, in addition to providing means for reversing the drive, also forms the drive pinion to the main driving gear, which is a press fit on the axle.

Two engine radiator units are fitted, one on each side of a car, to ensure adequate cooling under the difficult conditions of service under which cars operate. To ensure efficient temperature control two thermostats are fitted in the engine cooling water outlet pipe. The fan shafts of the radiator units are coupled to a central bevel gearbox, which is shaft-driven from the front of the engine. This bevel gearbox also provides the drive for the vee-belt pulleys of a 1000W, 24V constant voltage generator supplying current to a 160Ah battery of eighteen cells.

The four-wheeled bogies, one of which is illustrated herewith, have rigid frames of fabricated mild steel construction throughout. Their roller bearing axleboxes are carried on heavy coil springs. Each wheel is fitted with two brake shoes operated through clasp-type rigging by an 8in air cylinder. Air for braking



ARRANGEMENT OF DIESEL-MECHANICAL RAILCAR

RAILCAR IN ASSEMBLY SHOP

END BOGIE

CONTROL CABIN

purposes is supplied by a compressor on each engine. Another compressor, which is belt-driven from the engine cardan shaft, is fitted to supply air for braking in the event of an emergency such as might be the case if only one engine of the unit was available for service. In such a case the auxiliary compressor would ensure an ample supply of air to brake the cars on steep gradients.

In one of the photographs we reproduce can be seen the driver's controls, which are duplicated in the cabs at each end of the articulated car unit. It is of interest to note that all of the control gear is assembled in a self-contained cabinet, which is completely wired and tested before installation. The controls are connected to the various operating units by means of multi-pin plugs, after the cabinet is fitted in the cab. The cabinet itself is an assembly of separate self-contained units connected up by multi-pin plugs, and for maintenance or inspection each of the units can be readily removed without need for disturbing other parts of the assembly.

The control unit assemblies include a relay panel carrying all the relays for a power unit, which is mounted on a separate detachable base-board on the left-hand side of the cabinet. Forming another separate and easily detached unit is the control box let into the panel immediately in front of the driver. This assembly includes a forward and reverse switch, a change-speed control handle and a throttle control.

Grouped on a panel on the right-hand side of the cabinet are the air operated valves used for gearbox control, sanding gear and emergency brakes. On a bottom panel are grouped a series of foot switches for sanding control, the air-operated horns and a dead-man control, which is wired in parallel with the dead-man handle of the throttle control. This throttle control incorporates three air-operated cylinders arranged to give eight engine throttle positions, and through it both engines of the articulated car unit are given equal fuel injections, so that they develop equal power.

On the right of the control box another unit is set in the panel, which incorporates a fault detector switch and three indicating lamps. Two of these lamps are wired in parallel and they are unlighted during running whilst all the main units are operating normally. Should a fault develop in any power or transmission unit on either power set, the two lamps glow a bright red. To trace the source of the trouble all that the driver then has to do is to rotate the fault detector switch over a quadrant on which the names of the various units are engraved. The third lamp lights up as the switch crosses the circuit of the defective component and, if necessary, the power unit concerned can be cut out for the other engine to supply the tractive effect.

This method of indicating a fault, by means of lights, and determining its source has been adopted in preference to the automatic stopping of the engines. It is a warning which the driver cannot fail to see and enables him to continue to use the power available from one engine to its best effect to get to a convenient point to investigate the source of trouble. It will be appreciated that the system has much in its favour on difficult lines, where the stopping of a train without warning in the middle of a tunnel or on a long bridge would be inconvenient both to the passengers and the train staff.

The minimum possible number of gauges, &c., are fitted on the driver's panel; they include an engine revolution counter, a speed recorder, an ammeter, water temperature gauges and the engine starting switches. On a small panel at the top of the left-hand upright of the cabinet are grouped switches for the various train lighting circuits. On a pedestal on the driver's left is the lever for a Westinghouse straight air brake and controls for the pneumatically operated doors of the cars. A hand screw brake is situated against the side of the cab on the driver's left.

The Aircraft Carrier, the Battleship and the Submarine

(By our Naval Correspondent)

THE announcement early this year by Mr. Kimball, Secretary of the United States Navy, that the United States hopes to build ten 60,000-ton aircraft carriers in the next ten years is a clear indication of his country's determination to take the offensive in the event of a war with Russia. Russia, at war, would have neither the ships nor the need to gain and maintain control of sea communications, but with her large numbers of submarines and aircraft would do her utmost to deny their use to the Western Powers. She could not, however, be defeated if the N.A.T.O. navies adopted a purely defensive role, concentrating on the protection of their merchant ships and transports against attack by submarines, aircraft, raiders and mines. Nor would she be likely to be made to surrender by the invasion and capture of portions of her territory near her coast—the kind of offensive which is always open to a belligerent who has command of the sea. For Russia is a vast land with her centres of population and her factories distributed over wide areas. Although amphibious operations of this kind might well encourage underground movements among her satellite countries, they would probably do little more than immobilise a substantial portion of her army.

The most effective method of bringing home a war to Russia, according to military thinking, would be to bomb her railways—which are far from adequate for her requirements in war—her submarine ports, her power stations, and other essential installations and factories which are not already underground. Though Air Force enthusiasts in the United States—and to a lesser extent in this country—maintain that this is solely an Air Force task, there is little doubt that it could be carried out more effectively by medium range bombers from carriers operating off her coasts. The Korean campaign has already done much to open the eyes of senior Air Force officers in the United States to the vulnerability of the very long-range, subsonic land-based bomber—such as the "B.29"—to attack from jet interceptors. To quote one incident alone, in a raid last October by nine "B.29s" against a target in North-West Korea, the Russian-built "M.I.G.s" shot down three—a third of the total force—and damaged every one of the remainder. At the present time, when using "B.29s" to attack targets in extreme North-Western Korea—near the enemy's air bases in Manchuria—the United Nations are obliged to bomb by night—using radar—or, if raids are made by day, to accompany the bombers with an overwhelming force of fighters.

These new carriers are to have a flush deck, and the first of them—the U.S.S. "Forrestal"—should be completed late next year, at a cost of nearly £78 million. Her most striking feature is the width of her flight deck—252ft at one point—which will enable her to operate much larger and heavier aircraft—including the latest and longer-range jet fighters—than is possible from existing carriers. She will have a multiple system of catapults permitting, simultaneous launching of four aeroplanes—an essential requirement when immediate action is demanded. The problems involved in the construction of these carriers may well be eased by the new steam-operated catapult—a British invention—which was briefly described in a recent issue of this journal. It has been successfully tried out in the aircraft maintenance carrier "Perseus," and this vessel sailed recently for Philadelphia and Norfolk, Virginia, for a six weeks' visit to enable United States aviation experts to assess its potentialities.

While, however, these monster ships are required—indeed, are essential—for the particular circumstances of the moment, it is fortunate that the United States has the financial and labour resources to build them without undue detriment to her peacetime economy. For, apart from the disadvantage of vessels of this size—absence of docking facilities in the area of operations, to mention only one—they are likely to be a temporary rather than a long-term requirement. Improvements in radar and electronic computers are ensuring the rapid development of guided missiles and already the United States has produced a 12,000 lb rocket which can be guided throughout its trajectory. Concurrently the heavy detonating mechanism of the atom bomb has been much reduced and atomic explosive can now be used in rockets and no doubt also in torpedoes and mines and other conventional missiles. The firing of a guided missile with an atomic warhead from the deck of a ship may thus prove a more worthwhile operation than launching a bomber from a huge carrier. The aircraft has the advantage of longer range, but improvements in the radar control and in the rate of fire of anti-aircraft guns and the accuracy and increased range of surface-to-air rockets are making it more and more difficult for her to reach her target.

It is yet too early to visualise the kind of ship which will carry the Navy's main striking weapons of the future. It seems reasonable to assume, however, that the trend in construction will be towards reduction in the size of ships, as it was after the first world war, when, under the Washington Treaty, the size of capital ships was limited to 35,000 tons. Guided missiles are likely to replace flight decks with a return to the capital ship, which will be smaller,

faster and more expendable than the battleship as we know her to-day. It will no longer be necessary to build a larger ship to obtain increased fire power. If long-distance rockets can be employed successfully in naval ships the size of the weapon carrier will be of lesser importance, while the range of fire power, compared with the range of the naval gun, will be immensely increased. Navies refused to be swept from the seas by the invention of the aeroplane. They adapted the air medium for their own purposes and gained strength from it, and it may be anticipated that they will similarly adapt the guided missile, the atomic bomb and other destructive weapons, thus enhancing the value of sea power. A belligerent possessing the greater number of mobile bases for atomic attack, particularly at the opening stages of a war, will have a great advantage over an opponent.

There is, it should be noted, no technical or constructional difficulty in adapting submarines—the weapon carrier of the weaker naval power—to fire guided missiles. The United States has already reconstructed a submarine as a prototype for firing guided missiles of the flying bomb (V1) type, and trials carried out to date have given successful results. And if submarines are employed in large numbers—for each vessel could only carry one missile, whether of the V1 or V2 type—to fire atomically charged rockets on towns or thickly populated areas, they might prove a serious menace. While, however, the snort tube has reduced the difficulties of making an unobserved passage to the firing point, submarine detection methods are not standing still. It is now possible to detect a snort tube at an effective distance and Press reports from the United States refer to a new method of detecting submerged submarines at long distances by the use of a device which is very sensitive to water disturbances caused by a large moving object. Attacks of this nature would in any event be difficult to carry out if helicopter patrols, assisted by striking forces of surface vessels, were established in likely firing areas. Indeed, the guided missile and atomic explosive will in no way change the fundamental principle of naval warfare. Whatever the weapon or missile employed—guns, aircraft or guided missiles—if an offensive from overseas is to have decisive results the first essential is to gain and maintain effective command of the sea.

Humidifying Unit for Aircraft

TWENTY humidifying units, designed for humidifying the air to provide a comfortable atmosphere in the pressurised cabins of airliners flying at high altitudes, are being supplied by The General Electric Company, Ltd., for installation in Bristol "175" aircraft. Steam from the electrically-heated boiler of the unit may be fed into the cabin air supply at any convenient point and a 2in diameter steam pipe is provided for making the necessary connection. Water is pump-fed into the boiler through a float chamber, which automatically maintains the correct water level by actuating a micro-gap switch in the feed pump circuit. If a failure in the feed causes the level of the water in the float chamber to fall, a second micro-gap switch cuts out the heating elements. The humidifier unit is intended to be controlled by a "Humidistat," to come into operation when the relative humidity falls to 25 per cent, and to cut out when it rises between 60 and 70 per cent.

The boiler, with a capacity of approximately 1½ gallons, has ten pocket tubes mounted in a removable apparatus plate. Each tube accommodates one 750W cartridge element, thus giving a total loading of 7·5kW. The design of the unit is such that by varying the number of heating elements, any desired loading up to 7·5kW can be arranged. Also, by increasing the overall length of the unit slightly, the total loading may be increased to 10kW. Heaters for supply voltages ranging from 112V to 250V a.c. or d.c. can be accommodated. The quantity of steam generated by the 7·5kW unit is 19¼ lb per hour approximately, while for the 10kW loading approximately 26 lb per hour are produced.

The boiler is made of 20 gauge copper sheet and is enclosed by a cylindrical outer casing of aluminium sheet, with suitable foil lagging between the two. Asbestos sheet lagging insulates the float chamber and its removable cover from the boiler. The humidifying unit weighs 32 lb. Its overall dimensions are 18¾in long by 10¾in high, measured to the top of the steam pipe.

A Pressure Die Casting Foundry

IN order to meet the increased demands for pressure die castings, High Duty Alloys, Ltd., recently opened at its Slough works a new pressure die foundry equipped with a range of machines suitable for the production of castings weighing from 1 oz to 30 lb. Last week we took advantage of an invitation to inspect this new foundry, part of which can be seen in the photograph we reproduce on this page.

The foundry covers an area of some 7000 square feet and has a clear height of 20ft to the roof truss. At present twelve die casting machines are installed and there is sufficient room available to increase the number if required at some future date. The machines are spaced well apart to provide ample room for the operators to move in comfort and safety. In laying out the new foundry particular attention was paid to the working conditions, which leave little to be desired. It is well ventilated with a good standard of high level lighting in all parts and clean atmospheric conditions are maintained by the fitting of a large fume extractor to each machine. These fume extractors have special filters to prevent fire which may be caused by the ignition of residual oil.

All ingots supplied to the foundry have to comply with laboratory requirements and close control is exercised in all metal melting and processing. The ingots are melted down in two large, semi-rotary, gas-fired furnaces at one end of the shop. From these furnaces molten metal is transferred to gas-heated bale-out furnaces at each machine by means of ladles slung from an overhead travelling crane. Each bale-out furnace is set within easy reach of the machine operator, but kept well clear of a central gangway along which the castings are removed on stillages to the adjacent fettling section.

All services to the machines, such as gas, compressed air, temperature recording circuits, hydraulic lines, &c., are carried in trenches below floor level and covered with quickly removable chequer plates. Each machine is served by a hydraulic accumulator supplied by an individual pump situated in an adjoining pump house.

After seeing the new foundry we made a quick tour of the firm's extensive laboratories, where a considerable amount of research and development of new techniques for the manufacture and use of light alloys is in progress. In the physics laboratory, which was recently rebuilt to give a better lay-out, we were shown work now in progress in the measurement of residual stresses in aluminium alloy components by means of X-rays. Research was in progress with specially developed equipment to determine the usefulness of damping capacity as an indication of the presence of internal flaws in metal, and to determine the magnitude and variation of damping capacity at engineering stresses for engine and structural aluminium alloys. These are but two of the many interesting pieces of work in progress to assist in attaining higher standards of quality and wider applications for light alloys in industry.

Other laboratories were engaged in corrosion and surface protection research, heat treatment research, mechanical testing of all kinds, chemical and spectrographic analysis, and research, &c. A research foundry, which forms part of the laboratory, was mainly concerned with the development of aluminium and magnesium base alloys and high temperature alloys for turbine applications and the investigation of new alloys.

Aluminium as a Shipbuilding Material

A PAPER entitled "Aluminium as a Shipbuilding Material" was presented by E. C. B. Corlett, M.A., Ph.D., before the North-East Coast Institution of Engineers and Shipbuilders on Friday, February 22nd. We summarise it below.

Present-day applications of aluminium alloys began in 1930, although the first all-aluminium craft was built nearly sixty years ago, when either pure aluminium, having maximum corrosion resistance and low strength, was used, or a Duralumin alloy having exactly the reverse properties. Following the delays occasioned by the war, the use of the aluminium alloys for marine purposes has steadily expanded until it is now a fully fledged structural material, as instanced by the extensive use of the material for the 500ft long superstructure, of the liner "United States." In this ship, 2000

PRESSURE DIE CASTING FOUNDRY

tons of light metal are involved, including 1000 tons in the superstructure; 400 tons in funnel, boats, masts and davits, and 600 tons in the minor bulkheads and furniture, resulting in a direct weight saving of 2500 tons, and in an indirect saving of about 7500 tons.

For structural purposes alloys having a magnesium content of between 3 to 5½ per cent are recommended, and it is mentioned that a higher percentage of magnesium may lead to rapid corrosion if the material is stressed. The magnesium-silicide group of alloys is mentioned, and both are included for marine purposes in Lloyd's "Tentative Requirements for Quality and Testing of Aluminium Alloys for Shipbuilding Purposes."

For plates a 4 per cent magnesium alloy has proved suitable and sizes up to 30ft by 6ft can be rolled. In America the heat-treatable magnesium-silicide alloy is favoured, while in Britain the non heat-treatable aluminium-magnesium alloys are used. This latter alloy appears to be more suitable, since the advent of Argon Arc and Aircomatic welding has solved many welding problems, while the former are not suitable for welding unless subsequently heat-treated. The magnesium group does not lend itself to the extrusion process as readily as the magnesium-silicide group, which can be produced at a much greater rate, so that this latter alloy is generally used for sectional material in riveted construction. However, a change over to welding will affect the choice of alloy and the method of producing constructional sections, such as by rolling instead of extrusion.

Riveting technique is generally discussed for N.6 and H.10 alloys, and particulars of American practice with regard to heat-treatable rivets are given. The shear strength of N.6 rivets when driven hot or cold is quoted, and the standard design shear stress of 12 tons per square inch multiplied by the area based on the nominal diameter is suggested. Rivet clearances are given in a table which includes a note upon rivet lengths, spacing and edge distance.

The various welding processes are listed and sections of the paper are devoted to Argon Arc and Aircomatic welding methods, the advantages and disadvantages of each being noted, and a general statement is made concerning joint preparation.

Design problems are referred to and an instance given to illustrate the need for care concerning detail design. Turning to scantlings, a code of design practice is put forward which includes a relationship between steel and aluminium alloy for stresses, deflections and struts. With regard to the latter, it is recommended that the "Perry" formula be used, and tables give edge condition and effective length factors. Discussing actual constructional members, the effective width of plating to be included in a beam inertia calculation, is mentioned as being 20t for aluminium alloy as against 25t for steel if the Karman-Sechler formula is used. The question of brackets is treated and deck plating is considered as sheathed and unsheathed in both tension and compression. These four conditions are related to formulæ and an appendix to the paper gives details of experimental work carried out to establish the effect of sheathing on the failing loads of deck plating. A table gives particulars of a range of special bulb angles and tentative tables of scantlings for large deck houses are included in which it is stated that a weight ratio of 0·36 is achieved.

South African Engineering News

(By our South African Correspondent)

Newly-Formed Iron and Steel Company

The Dominion Iron and Steel Corporation, a newly-formed company which has an authorised capital of £1,500,000, has acquired the South African rights of the Krupp-Renn process, which will be employed in the projected iron and steel works to be started at Airlie in the Eastern Transvaal, between Machadorp and Nelspruit. A low-grade iron ore will be worked, using cheap duff coal, hitherto scrapped by the collieries as unsaleable.

Until the erection of a rolling mill, the company intends to sell its output of nodules having an iron yield of 90 per cent, as high-grade scrap iron. It is estimated that the yield will be about 48,000 tons a year.

Brick-Making Machinery

The rapid expansion of the brick-making industry in the Free State has provided machinery suppliers with a delivery problem which has been difficult to meet from overseas factories, and which has been solved by a South African firm, A.S.E.A., with works in Pretoria. This firm has built, under licence from T. C. Fawcett, Ltd., of Leeds, a double simplex stiff plastic brickmaking machine. This arrangement has effected a considerable saving on import permit allocations and a much quicker delivery.

The machine has been manufactured almost exclusively from South African materials, and is said to be an improvement on older types, being fitted with top and bottom pressure motion, which gives an equal live pressure on top and bottom of the brick. It has a new toggle arrangement of massive proportions fitted with renewable bushes with which the pressure is sustained six times as long as with any eccentric motion, allowing time for material to consolidate, and escapes to flow at lowest possible velocity. All parts of the machine are in view during operation, and the moulding table and footstep are removable by releasing four bolts, without dismantling any other parts. The footstep, which is of very large dimensions, practically eliminates wear, and the pugmill is readily accessible and fitted with a pug shaft, whereby the replacement of wearing parts can be effected in minimum time. The impulse oiler, complete with air pump and oil tank, pipes and sprayers, giving a regular supply of oil and operating only when the machine is running, uses less oil than other methods. Weighing approximately 26 tons, this machine turns out 2500 pressed bricks per hour and has been delivered to the Coronation Brick and Tile Works, Bloemfontein, where various other brickmaking machines have previously been installed.

A Large Gear Wheel

THE largest gear wheel ever made in South Africa has been generated in Benoni by Precision Equipment (Pty.), Ltd., on a 16ft hobbing machine which the company recently installed. With a diameter of 15ft this gear wheel forms a girth ring for driving a cement mill.

In the heavy shop equipment of this company are included two of the largest machines of their kind in the southern hemisphere—a 16ft gear hobbing machine and a 300-ton vertical boring machine of similar capacity. These massive machines will be used essentially for the manufacture of large gears and pinions required by the South African mining and other industries.

CHEMICAL WORKS' SAFETY CONFERENCE.—The Association of British Chemical Manufacturers is holding a Chemical Works' Safety Conference at the Palace Hotel, Buxton, Derbyshire, from Friday to Sunday, May 2nd to 4th. Papers to be read and discussed include "Safety in the Laboratory and on the Plant," by Dr. L. J. Burrage; "Toxic Dusts in Industry," by Mr. J. S. Evans, M.A., B.Sc.; "The Relation Between Plant Strength and Dust Explosion Relief," by Dr. D. Matheson, M.A.; "Safety in Plant Maintenance," by Mr. C. A. Beaton; "The Safe Transportation and Storage of Chemicals," by the Works' Safety Committee of the Association of British Chemical Manufacturers. The chairman of the conference will be Mr. J. Davidson Pratt, C.B.E., Director of the Association. The fee per delegate is £8 8s.; it includes full board and accommodation from and including dinner on Friday evening, up to and including lunch on Sunday, free preprints of the papers and one copy of the subsequent published proceedings Forms of application and detailed programme, together with information regarding travel between London and Buxton, can be obtained from the Association of British Chemical Manufacturers (Intelligence Officer), 166, Piccadilly, London, W.1.

French Engineering News

(By our French Correspondent)

Considerable efforts are being made in France to install plant for drawing off pit gas from the mines and using it for fuel. This method is said to promote safety in the mines and to have important economic advantages. In the Aciéries Charles et Sainte Fontaine, compressor equipment is being installed so that the gas may be used by motor trucks. At Lieven the gas will be transported to the coking plants. Charbonnages de France has been making a detailed study of the question, and in a recent report pointed out that the cost of the gas amounted to no more than 1·70 francs per cubic metre; the calorific value of the gas was put at 9000, compared with coal gas at 4·50 francs per cubic metre, and a calorific value of 4300. The most important fields to be worked will be in Lorraine and in the Nord and Pas de Calais. Recovery will only be carried out where the cost is not too great and where the quantity of gas is dangerous. It is expected, for example, that for the whole of France it will not be possible at first to recover more than 300,000 cubic metres per year. The following detailed figures are given. At Lieven about 6000 cubic metres could be recovered per day, although it is estimated that at least another 6000 cubic metres would be lost. This gas is good and is far better, in some respects, than town's gas. It has one inconvenience, however; it contains oxygen, thus tending to oxidise the pipes in which it is contained. Special burners would have to be installed to use it. Gaz de France, therefore, is not interested in the gas, but it has been suggested that it might replace coal gas for use at coking plants. This solution is considered the most acceptable and within a few weeks gas from Lieven will be piped to the coking plant at Drocourt, at a rate of some 6000 cubic metres daily. As the technique and installations develop the total quantity of gas produced will increase.

* * *

Details of a project for the construction of a dam and hydro-electric plant at Serre Poncon, on the Basse Durance, in the region of Marseilles, have now been made known. It is estimated that the new reservoir will hold about 1200 million cubic metres of water and that its electricity production capacity should be in the region of 1000 million kWh per year. It is announced that all the details of the barrage design have been completed and that irrigation of agricultural land will benefit when the construction is completed, as well as the general benefit which will be derived from the production of electricity. The engineers have also stated that the size of the reservoir should help attenuate some of the damage caused by flooding of rivers in the area. It is believed that work on the new barrage will start shortly and that the construction and installation will be completed by 1958. The work will include the construction of an 80km canal which will take an inflow from several rivers.

* * *

Another section of the electrified railway line between Paris and Lyon has been opened. Electric trains now travel as far as Chalon-sur-Saône. Until last month the electrified section was open only to Dijon.

It is expected that the line will be completed during June and that the first Paris–Lyon electric train will run on July 1st. The first train to run over the whole line should complete the journey in 4 h 20 min at an average speed of 120km per hour.

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It is reported that a new type of gas turbine engine designed by engineers of S.I.G.M.A. develops 1000 h.p. and weighs 14 tons. Electricité de France has already ordered a series of these generators and the Renault Régie is examining the possibility of using one for a 48 tons locomotive. S.I.G.M.A. is investigating the possibilities of a smaller engine developing 300 h.p. based upon the same design, for use in heavy lorries.

Industrial and Labour Notes

Changes in Wage Rates

The Ministry of Labour has stated that changes in wage rates which came into effect during January resulted in an aggregate increase of approximately £352,000 in the weekly full-time wages of about 1,105,000 workpeople. Among those who received increases were workers in the vehicle building industry, and in iron ore mining in certain areas, and women workers in the engineering industries.

The Ministry says that, of the total increase of £352,000, about £133,000 resulted from arbitration awards, £92,000 from arrangements made by Joint Industrial Councils and similar bodies established by voluntary agreement, £82,000 from the operation of sliding scales based on the index of retail prices, £31,000 from Orders made under the Wages Councils Acts, and the remainder from direct negotiations between employers and workpeople or their representatives.

Trade Disputes

The number of stoppages of work through industrial disputes in the United Kingdom, reported to the Ministry of Labour as beginning in January, was 121. In addition, three stoppages which began before January were still in progress early in that month. In these 124 stoppages it is estimated that about 26,100 workpeople were involved directly and indirectly during January, and that 79,000 working days were lost. The majority of the stoppages occurred in the coal mining industry, in which, in the aggregate, 28,000 working days were lost in January by 16,100 workers.

Industrial Production

The index of industrial production (1946=100), which is prepared by the central statistical office of the Treasury, has been estimated provisionally at 137 for December, 1951, compared with a revised figure of 152 for November. Figures for the corresponding months of 1950 were 140 for December and 153 for November. The Treasury says that, provisionally, the index for the whole of 1951 is 144, compared with 140 for the year 1950.

In the latest number of its *Bulletin for Industry*, the Treasury comments that industrial output has stopped rising. Compared with an annual increase of 8 per cent or so in 1948–50, it was only 3 per cent higher in 1951 than in 1950, and most of that smaller increase occurred in the first half of the year. In the second half the increase tapered off and by the closing months, the *Bulletin* says, production was actually lower than a year earlier. The industrial labour force last year continued to rise at much the same rate as in earlier years—about 2 per cent annually—which suggests that there was no significant increase in productivity.

With a few exceptions, the *Bulletin* goes on to say, there was a falling off in the rate of increase in output, or an actual decline, throughout manufacturing industry. In the metals, engineering and vehicles group of industries, the rate of rise fell sharply away during last year, and by September–October output was down to the level of the same period of 1950. Within that group, the engineering, shipbuilding and electrical industries closely followed the same trend, though in October they were still running at a higher level than a year earlier. Mining, the *Bulletin* points out, was the only major industry where last year production rose more rapidly than a year earlier. But the acceleration was slight, and the improvement does not seem to be continuing into 1952. In the first seven weeks of this year, coal output, deep mined and opencast, was 1·9 per cent up on a year earlier, as against a rise of 3·4 per cent in the last quarter of 1951. Output per man-shift (all workers) has averaged about 3 per cent lower this year, a decline, the *Bulletin* adds, which has been "more than offset by a 10,000 increase in manpower and an increase in the number of shifts worked."

Production Technology and Management Scholarships

The Ministry of Education has announced that, with the object of assisting industrial productivity in this country, seventy-five scholarships are to be awarded this year for the study of production technology and management in selected universities or technological institutes and in industrial undertakings in the U.S.A. The Mutual Security Agency is to supply the dollar equivalent to meet tuition fees, travelling expenses in the U.S.A., and suitable maintenance allowances, the approximate cost being 250,000 dollars. Return passages to the U.S.A. will be paid for from public funds.

In former years, the Ministry of Education says, most of the candidates qualifying for the awards have been employees of the country's larger firms and organisations. This year, it is hoped that employees of the smaller firms, which form such a considerable part of the national economic system, will share in the scheme to a greater degree. The awards are to be made in two groups. In the first group, forty scholarships, available for the study of management and normally tenable for a period of nine months, will be open to people between the ages of twenty-five and thirty-five of adequate educational standard, who are potential managers or are occupying responsible positions in industry, or who propose to teach management subjects. A minimum of three years' industrial experience is a condition of entry. In the second group, thirty-five scholarships for the study of production technology combined with management and normally tenable for a period of one year, will be open to students holding good honours degrees in either pure science or technology, who have had at least two years' industrial experience and are now working in industry or research associations, or are teaching in universities or technical colleges.

Successful candidates will be expected to leave for the U.S.A. early in September next, and the closing dates for applications are April 16th and 30th for the technological and management awards respectively. Full details of the scholarships may be obtained from the Ministry of Education (F.E. Division 1), Curzon Street, London, W.1.

Industrial "Self-Help" Scheme

The Ministry of Supply has stated that representatives of industry in areas containing a number of important war factories are being invited to form small "self-help" panels to assist with labour, materials, plant and any other facilities they may have available in the event of damage occurring in wartime. The Ministry says, of course, that the main task of carrying out repair work to factories damaged in war would fall upon the works and buildings emergency organisation as part of the national civil defence arrangements.

It is thought, however, that factories engaged on important war work could themselves introduce and operate a voluntary system of self-help and could thereby provide immediate first-aid from their own resources to get factories back into production as quickly as possible. Where repair work could not be undertaken by the panels, the matter would be referred immediately to the works and buildings emergency organisation. The Regional Controllers of the Ministry of Supply are preparing to set up these panels in their respective regions.

The Manpower Situation

During a debate on manpower and productivity in the House of Commons last Monday, the Minister of Labour, Sir Walter Monckton, Q.C., said that at the end of July, 1951, unemployment in this country was lower than at any time since the war, but some adverse tendencies had already then begun to show themselves. Since that lowest figure of July, the Minister continued, there had been an increase in unemployed of 193,000, and there had also been some easing of the pressure on demand for labour, as shown by the vacancies notified to local offices of the Ministry.

Later in his speech, the Minister observed that, during 1951, unemployment in the metals, engineering and vehicles industry increased by 118,000. There was, he said, anxiety about the shortage of raw materials, and there were difficulties in the period where there was a substantial change in the classes of production; yet unemployment in January this year was slightly lower in those industries than it had been a year previously and had increased by only 12,000 between July last and January. Sir Walter then went on to talk about the metal-using industries generally, remarking that the overall size of those industries would be conditioned largely by the amount of steel available. But, in any case, he said, the development in the national interest of certain classes of production and the curtailment of others must account for the movement of labour in and out of individual establishments.

In the engineering industry especially, Sir Walter continued, the movement of workers must be effected by the changes in production which would be brought about by decisions taken to revise the defence programme, to reduce the production of plant, machinery and vehicles for the home market, to limit production of metal-using goods, and, above all, to foster exports. Sir Walter said that he could not give figures which illustrated the size of that operation, part of which would no doubt take place by the switch of production within individual establishments. One big item, however, was a net increase of something like 60,000 required for the aircraft and Royal Ordnance factory programmes. At the moment, Sir Walter observed, there were more than 78,000 outstanding vacancies in the engineering industry registered at local employment offices, and 32,000 for skilled occupations. The most pressing difficulty of all was the shortage of skilled workers.

Economic Conditions in the U.S.A.

The latest volume in the series of overseas economic surveys produced by the Board of Trade deals with economic and commercial conditions in the United States. It has been prepared by members of the staff of the British Embassy in Washington and is a completely revised edition of the volume originally published in 1948.

The Board of Trade has stated that the purpose of this survey is to provide for British readers a source of general information about the U.S.A., which may not be readily available elsewhere in so condensed a form. An introductory section outlines the position of the U.S.A. in world economy and indicates what structural changes have taken place in recent years. It also gives details of the relationship between the Federal Government and the State governments and the relationship between the legislature and the executive. Other chapters include information on population, labour and social relations, natural resources as, for example, oil, coal, metals and water, and particulars of agriculture and food production in the U.S.A. In addition, there is information about individual industries, scientific and industrial research, transport and communications, the national income and finance generally. The final chapter in the survey deals with United States trade and includes descriptions of foreign trade and policy and customs regulations, as well as referring at some length to British exports to the U.S.A. and to the prospects of British exporters.

The survey is published by H.M. Stationery Office, at 8s. 6d.

Notes and Memoranda

Air and Water

THE ROYAL AERONAUTICAL SOCIETY.—The annual garden party of the Royal Aeronautical Society is to be held again this year at the White Waltham aerodrome on Sunday, June 15th.

NAVAL HOSPITAL SHIP.—Barclay Curle and Co., Ltd., has laid the keel of a new hospital ship for the Royal Navy. This ship, which will be of about 10,000 tons gross, has been specially designed for hospital service.

Miscellanea

SIR WILLIAM J. LARKE MEDAL.—The council of the Institute of Welding has conferred the Sir William J. Larke Medal upon Mr. W. S. Atkins, B.Sc., M.I.C.E., for his paper, "Continuous Welded Structures—Abbey Works, Port Talbot." Papers highly commended by the examiners were those of Mr. J. Latimer, on "Automatic Welding," and Mr. A. R. Moss on "The Welding of Cast Iron."

NUTS AND BOLTS.—The Minister of Supply has made an Order increasing the controlled maximum prices of bolts, nuts, &c. The increased prices reflect the increase in the price of steel, under the Iron and Steel Prices Order, 1952, together with increases in the costs of the bolt and nut industry, including increases in wages, transport and fuel costs. The Order came into effect on February 27th.

INCREASED BULK SUPPLY CHARGES FOR ELECTRICITY.—The British Electricity Authority has announced that, because of continuing rises in costs, prices of electricity to the Area Electricity Boards will be increased as from April 1st next. On that date the kilowatt demand charge under the tariff fixed with effect from April 1st, 1951, will be increased from £4 2s. 6d. to £4 5s. 6d. The running charge remains at 0·33d. per unit, subject to a coal price adjustment of 0·0007d. per 1d. variation in the price of fuel, in the area concerned, from a basic figure of 38s. per ton.

OIL PIPE-LINE.—The 560-mile-long, 30in pipeline, of the Iraq Petroleum Company, which links Kirkuk in North Iraq to Banias in Syria, will be ready for commissioning in April. A double line of 12in and 16in pipe already connects Kirkuk with the terminal at Tripoli, Lebanon, and the new line, when completed, will convey 14 million tons of crude oil per annum to the Mediterranean coast. The material for the pipe-line, involving 183,000 tons of steel pipe, was supplied from the United States, while the equipment for the pumping stations has come from the United Kingdom.

SYMPOSIUM ON "FATIGUE."—The Ergonomics Research Society is to hold a symposium on "Fatigue" at the College of Aeronautics, Cranfield, near Bletchley, from Monday to Thursday, March 24th to 27th. The opening session of the symposium is at 2.30 p.m. on Monday, March 24th, when Sir Frederick Bartlett, F.R.S., and Professor G. P. Crowden will speak on "Psychological Criteria of Fatigue." Sir Victor Goddard, Principal of the College of Aeronautics, will preside. Full particulars about membership of the symposium may be obtained from Mr. S. H. Mound, 71, Princes Square, London, W.2.

CARBON BLACK FILM.—The developments in the production of carbon black have been recorded in a film entitled "A Study in Black," which has been produced for the American company, Godfrey L. Cabot, Inc. The 16mm sound film is in full colour and was made at the Ville Platte Furnace plant of the company. It deals with the channel and furnace processes for making carbon black, discusses its properties and illustrates the widespread application of the product in the commercial field. The film, which has a running time of twenty minutes, can be obtained on free loan by responsible authorities from Carbon Black, Ltd., Stanlow, Ellesmere Port, Cheshire.

THE ROYAL SHOW.—The Royal Agricultural Society has stated that thirty-eight entries have been received for the Silver Medal award for new implements to be exhibited at this year's Royal Show at Newton Abbot. The sub-committee, which deals with this matter, has recommended acceptance for judging of nine implements, including four deferred from last year's show. Five others have been deferred for official test and re-entry in the 1953 show, which is to be held at Blackpool. The Society has also announced that the 1954 Royal Show will be held in Windsor Great Park. It will be the show's fourth visit to Windsor, the last occasion being in 1939, which was the centenary year of the Royal Agricultural Society.

STANLOW REFINERY.—The catalytic cracking unit which has been built at the Stanlow Refinery of the Shell Petroleum Company, Ltd., at a cost of £8,000,000, is now in commercial operation and brings the total output of the company up to 8·5 million tons per annum. With the completion of this unit, petrol supplies will be increased, also the output of chemical solvents, and sufficient feed stock will be made available to the sulphur recovery plant for the production of 10,000 tons of sulphur.

MAGNESIUM ADVISORY COMMITTEE.—The principal companies of the United Kingdom's magnesium industry have formed a consultative and advisory body to be known as the Magnesium Advisory Committee. Its broad objective is to encourage expansion in the production and applications of magnesium and its alloys. Initial activities will be to hold regular discussions on general policy and technical matters as between the member companies, and to serve as the official liaison body for negotiations with the Ministry of Supply, Ministry of Materials and other Government departments on all related subjects, at present with particular reference to the defence programme. Membership is open to all companies engaged in the production, casting and/or hot working of magnesium or its alloys, with the provision of approval of applications by the committee. For the present meetings are being held at Distillers House, St. James's Square, London, S.W.1, and Mr. R. G. Wilkinson, deputy chief metallurgist, Magnesium Elektron, Ltd., Bath House, 82, Piccadilly, London, W.1, is acting as honorary secretary.

INTERNATIONAL SEAWEED SYMPOSIUM.—An International Seaweed Symposium, sponsored by the Institute of Seaweed Research, is to be held in the Department of Zoology, Edinburgh University, from July 14th to 17th. Final arrangements have now been completed by the organising committee, which has the co-operation of corresponding delegates in Australia, Canada, Chile, France, Germany, New Zealand, Norway, South Africa, Spain, Sweden and the United States. The symposium will deal with the following major topics: phycology, algal chemistry, harvesting technology, utilisation in industry, medicine and agriculture, and world seaweed resources. Contributed papers are to be of about thirty minutes' duration and adequate time will be allocated for discussion. On the day prior to the opening of the symposium an excursion is being arranged to the university town of St. Andrews and the Gatty Marine Laboratory. During the symposium there will be excursions to the Institute of Seaweed Research and to Dunbar, where mechanical harvesting techniques will be demonstrated. Accommodation has been reserved at the University Students' Hostels, with hotel accommodation as an alternative. Registration and accommodation forms may be had on application to Mr. T. W. Summers, at the Institute of Seaweed Research, Inveresk, Midlothian, Scotland.

Personal and Business

LONDON TRANSPORT announces the appointment of Mr. C. E. Cadwallader as a principal executive assistant.

MR. G. W. J. BRADLEY, F.R.I.C., has been appointed divisional carbonisation general manager of the East Midlands Division of the National Coal Board.

HENRY WIGGIN AND CO., Ltd., states that Mr. A. B. Graham, manager of the Zenith Works, Thornliebank, Glasgow, has been elected to its delegate board.

BRUCE PEEBLES AND CO., Ltd., Edinburgh, states that Mr. R. W. Flux has been appointed to the newly created post of chief engineer of the transformer department.

MR. L. E. MEEKS and Mr. H. R. Walton, formerly directors of Electroflo Meters Company, Ltd., have joined Elliott Brothers (London), Ltd., Century Works, Lewisham, S.E.13.

RUSTON AND HORNSBY, Ltd., states that its Birmingham branch office is to be moved on March 18th to Dilworth House, 190, Broad Street, Birmingham, 15 (telephone, Midland 2811).

MR. HAROLD ORMISTON, B.Sc., A.M.I.C.E., has been appointed assistant engineer (permanent way), civil engineer's department, York, in the North-Eastern Region of British Railways.

THE SNOWY MOUNTAINS HYDRO-ELECTRIC AUTHORITY announces that, as from March 10th, the address of its London office will be 18, St. George Street, Hanover Square, W.1 (telephone, Mayfair 7317).

METROPOLITAN-VICKERS ELECTRICAL COMPANY, Ltd., announces the following appointments: Mr. D. J. Crowther, personnel manager; Mr. A. C. Ellis, manager of the Cardiff office in succession to the late Mr. H. Coope.

VISCOUNT RUNCIMAN was elected President of the Chamber of Shipping of the United Kingdom, in succession to Mr. C. E. Wurtzburg, at the annual general meeting of the Chamber. Mr. D. F. Andersen was elected vice-president.

THE GLASGOW CORPORATION has redesignated the post of general manager as chief engineer and general manager, Glasgow Corporation Water Department. This appointment is held by Mr. Stanley D. Canvin, B.Sc. (Eng.), M.I.C.E.

THE QUASI-ARC COMPANY, Ltd., Bilston, Staffs, states that, as from April 1st, the sales and service of Unionmelt automatic welding plant, powder and wire will be transferred to its associated company, Fusarc, Ltd., Team Valley, Gateshead-on-Tyne, 11.

MR. G. DARNLEY SMITH, managing director of Bush Radio, Ltd., and Cinema-Television, Ltd., has been elected chairman of the Radio Industry Council. Mr. G. A. Marriott, a director of the Marconi-Osram Valve Company, Ltd., has been elected vice-chairman.

BRITISH INSULATED CALLENDER'S CABLES, Ltd., announces the retirement of Mr. W. G. Holmes after thirty-eight years as manager of the Southampton branch. His successor is Mr. E. Hitchen, who joined the former Callender's Cable and Construction Company, Ltd., in 1920.

THE NATIONAL COAL BOARD has appointed Dr. William Reid to be chairman of the Scottish Divisional Board in succession to Lord Balfour, who resigned at the end of last year. Dr. Reid was production director of the Scottish division from its formation in September, 1946, until becoming its deputy-chairman at the end of 1949.

Launches and Trial Trips

STANLEY ANGWIN, cable ship; built by Swan, Hunter and Wigham Richardson, Ltd., for Cable and Wireless, Ltd.; length overall 315ft, breadth moulded 41ft, depth moulded to upper deck 25ft 9in, deadweight 2200 tons, load draught 19ft, operating range 10,000 miles, coiling capacity 18,850 cubic feet; two sets of triple-expansion engines, 1450 i.h.p. total at 104 r.p.m., two multitubular Scotch boilers. Launch, February 11th.

LONDON VICTORY, motor tanker; built by the Furness Shipbuilding Company, Ltd., for London and Overseas Freighters, Ltd.; length between perpendiculars 525ft, breadth moulded 71ft, depth moulded 39ft 3in, deadweight 18,100 tons, summer draught 30ft 5½in; twenty-seven oil cargo tanks, two pump rooms, four 400 tons per hour duplex steam cargo pumps, corrugated bulkheads; N.E.M.-Doxford single-acting, two-stroke oil engine, six cylinders, 670mm diameter by 2320mm combined stroke, 6800 b.h.p. at 119 r.p.m.; steam deck machinery, two Scotch boilers, two 60kW steam-driven generators, one 25kW diesel-driven generator. Trial, February 19th.

MALEKULA, cargo ship; built by Barclay, Curle and Co., Ltd., for Burns Philp and Co., Ltd., Sydney; length 336ft, breadth 47ft, depth to shelter deck 27ft 6in, 3786 gross tons; twelve passengers, electric deck machinery, four 150kW diesel generators; Kincaid-B. and W. two-cycle, trunk piston oil engine, eight cylinders, 500mm diameter by 900mm stroke, 2200 b.h.p. at 150 r.p.m. Trial, February 20th.

SCOTTISH EAGLE, motor tanker; built by Swan, Hunter and Wigham Richardson, Ltd., for the Scottish Tanker Company, Ltd.; length between perpendiculars 515ft, breadth moulded 69ft 6in, depth moulded 38ft 4¼in, deadweight 15,850 tons on 30ft summer draught, service speed 14 knots; Swan, Hunter-Doxford oil engine, six cylinders 670mm diameter by 2320mm combined stroke, 6400 b.h.p. at 115 r.p.m., two Scotch boilers. Launch, February 25th.

BRITISH TALENT, oil tanker; built by R. and W. Hawthorn, Leslie and Co., Ltd., for the British Tanker Company, Ltd.; length overall 643ft, breadth moulded 81ft, depth moulded 44ft 6in, deadweight 28,100 tons; thirty cargo oil tanks, one pump room with three turbine-driven cargo pumps; one set of double-reduction geared turbines of 13,750 s.h.p., two Foster-Wheeler water-tube boilers, supply steam at 450 lb per square inch and 750 deg. Fah.; two geared 600kW turbo-alternators, one steam 50kW generator and one 150kW diesel alternator. Trial, February 27th and 28th.

British Patent Specifications

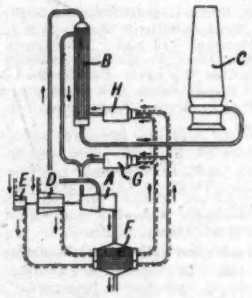
When an invention is communicated from abroad the name and address of the communicator are printed in italics. When an abridgment is not illustrated the specification is without drawings. The date first given is the date of application; the second date, at the end of the abridgment, is the date of publication of the complete specification.

Copies of specifications may be obtained at the Patent Office Sales Branch, 15, Southampton Buildings, Chancery Lane, W.C.2, 2s. each.

GAS TURBINES

665,416. October 11, 1949.—Gas Turbines and Blast-Furnaces, Maschinenfabrik Oerlikon, of Oerlikon, near Zürich, Switzerland.

This invention relates to an industrial plant comprising a gas turbine and a blast-furnace supplied with gas from the gas turbine. In the drawing *A* is the gas turbine, *B* the heater for the compressed gas taken from the turbine, *C* the blast-furnace, *D* the air compressor, and *E* the gas compressor. The exhaust gases of the gas turbine preheat compressed air and compressed gas in a heat exchanger *F*. A combustion chamber *H* is arranged in advance of the heater *B*. The combustion gases heat compressed gas on its way to the blast-furnace and then



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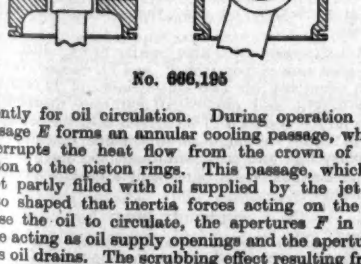
flow as operating medium to the gas turbine *A*. Gases from a combustion chamber *G* are also led to the gas turbine. The combustion chambers *G* and *H* are supplied with air and gas from the compressors *D* and *E*; they can also be combined into a single apparatus. Since the heater *B* is under pressure on both sides its dimensions become smaller and consequently the manufacturing costs lower. The gas turbine, compressor and combustion chambers can be of any suitable type, and the consumers of compressed gas may be blast-furnaces and other industrial furnaces. A modified arrangement is also shown in the specification.—*January* 23, 1952.

INTERNAL COMBUSTION ENGINES

666,195. July 12, 1949.—Pistons, Davey, Paxman and Co., Ltd., Standard Ironworks, Colchester, Essex. (*Inventor: David Maresco Pearce.*)

The invention relates to the construction of oil-cooled pistons. Referring to the drawings, the interior of a piston *A* has gudgeon pin bosses *B* which are formed integral with a coned member *C* extending to the centre *D* of the crown of the piston. The piston bosses and cone are made as a single casting with a cored passage *E* surrounding the upper part of the cone *C* adjacent the external piston ring belt. During manufacture the core which forms the passage *E* is supported through apertures *F* and *G* in the cone, which serve subse-



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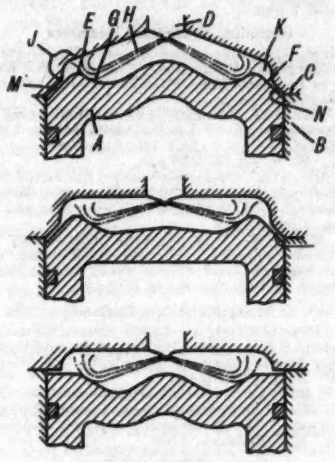
quently for oil circulation. During operation the passage *E* forms an annular cooling passage, which interrupts the heat flow from the crown of the piston to the piston rings. This passage, which is kept partly filled with oil supplied by the jet *H*, is so shaped that inertia forces acting on the oil cause the oil to circulate, the apertures *F* in the cone acting as oil supply openings and the apertures *G* as oil drains. The scrubbing effect resulting from this oil circulation ensures a high rate of heat transfer from the hottest parts of the piston to the oil. Uniform cooling of the piston ring belt is achieved by making the passage *E* to extend around the full circumference of the piston and maintaining it in a uniform sectional shape. The specification also shows the invention applied to two-part piston designs.—*February* 6, 1952.

666,220. June 18, 1948.—Internal Combustion Engines with Open Compression Chamber, Aktiebolaget Atlas Diesel, of Sickla, near Stockholm, Sweden.

In the accompanying drawings compression chambers for two and four-stroke engines are shown. The two upper views are axial sections of the compression chamber of two different types of two-stroke engines, while the lower view is a section of the compression chamber of a four-stroke engine.



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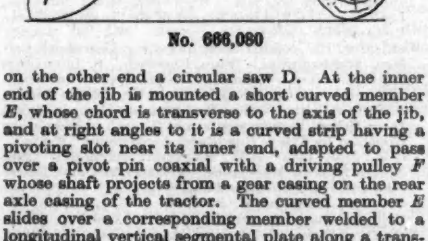
In the drawings *A* is the head of an engine piston, *B* the cylinder wall, *C* the cylinder head, and *D* a central fuel injection valve. The head of the piston has an annular ridge or crest *E* extending at a distance from the periphery and formed between a peripheral surface *F* and an annular deflection surface *G* inclined relatively to the cylinder axis at such an angle that fuel jets *H* directed towards the surface *G* are deflected towards a cavity formed in the cylinder head and extending radially towards a wall portion in the cylinder head shown by the bracket *J*. A portion of this cavity *K* is confined by the wall portion *J* of the cylinder head which is located at a greater distance from the fuel injection valve than the ridge or crest and a portion of the surface *F* adjacent the ridge or crest *E*. The deflected fuel jets cross the cavity portion *K*, which, when the piston approaches top position, is crossed by air streams expelled from a slot *M* formed between the peripheral surface of the piston and an annular surface *N* on the cylinder head. The specification also illustrates the application of the invention on an opposed-piston engine.—*February* 6, 1952.

AGRICULTURAL MACHINERY

666,080. April 28, 1949.—Jib Saw Attachment for Tractors, Morris Hunter, "Fernwood," 5, Peggy's Wicket, Beamish, Durham.

Referring to the drawing, the saw jib comprises a tube *A* having at its outer end a transverse shaft *B*, on one end of which is mounted a belt pulley *C* and



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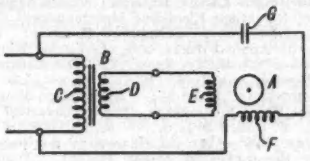
on the other end a circular saw D. At the inner end of the jib is mounted a short curved member *E*, whose chord is transverse to the axis of the jib, and at right angles to it is a curved strip having a pivoting slot near its inner end, adapted to pass over a pivot pin coaxial with a driving pulley *F* whose shaft projects from a gear casing on the rear axle casing of the tractor. The curved member *E* slides over a corresponding member welded to a longitudinal vertical segmental plate along a transverse vertical plate drilled to receive four stud bolts *F*. When these bolts are screwed up the assembly is secured to the pulley assembly casing. Mounted along the jib is a triangular sliding bracket or frame *G*, to which is secured a cross member, the ends of which are adapted to be coupled to the cross bar *H* of the normal lifting and lowering mechanism of the tractor. The specification also shows the device combined with a saw bench.—*February* 6, 1952.

ELECTRICAL ENGINEERING

666,268. March 15, 1949.—Operating a small Two-Phase Motor from a Single-Phase Supply, Ferranti, Ltd., of Hollinwood, Lancaster, and Denis Williamson, of the company's address.

The invention relates to systems for operating a small two-phase motor from a single-phase supply at a voltage exceeding the working voltage of the motor. The drawing shows a two-phase induction motor *A*, a step-down transformer *B*, the primary winding *C* being connected to the supply. The secondary winding *D* of the transformer has output terminals across which is connected field winding *E* of the motor. The other field winding *F* in series with a capacitor *G* is connected across the input terminals. The capacitor is such that the voltage across winding *F* in series with it is approximately the working voltage of the motor, whilst the capacitor produces a sufficient phase shift of the current in this wind-



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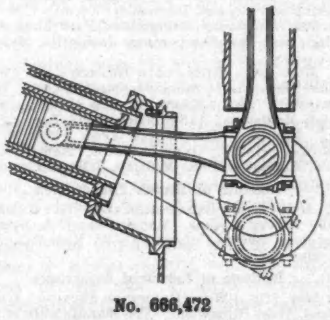
ing. Taking a numerical example: suppose the supply voltage is 230V at 50 c/s, the working voltage of the motor is 50V, and the power rating of the motor is 1W; a suitable capacitance of the capacitor is found to be about 1 microfarad, this value reducing the voltage across field winding *F* to approximately the working voltage and ensuring a sufficient phase shift. An advantage of the invention over known systems is that the size of the stepping-down component may be reduced since it has to energise only one field winding instead of two. Another advantage is that a capacitor of smaller capacitance has to be used, since an increased voltage drop has to be developed across it. The specification illustrates another form of the invention where transformer is an autotransformer.—*February* 6, 1952.

COMPRESSORS AND BLOWERS

666,472. May 8, 1948.—Air Compressing Plant, C. H. Johnson (Machinery), Ltd., of Adswood Road, Stockport, Charles Herbert Neesom, 20, Kingsley Drive, Cheadle Hulme, Brian Burton Dearden, 23, Thorn Road, Bramhall, and John Arthur Hartley, 2, Glendene Avenue, Bramhall.

This invention relates to air compressing plant actuated by an internal-combustion engine mounted upon a wheeled chassis or undercarriage. The compressor cylinders are mounted over a side opening in the crankcase of an existing internal-combustion engine with vertical cylinders. The compressor cylinders having their axes inclined at an angle less than 90 degrees to the vertical. Each



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connecting-rod of the engine is forked at its big-end to accommodate the big-end of the compressor connecting-rod. The general arrangement is shown in the accompanying drawing. A two-cylinder vertical engine has compressor cylinders built on as described, and designed to deliver 110 cubic feet of air per minute, without any increase in overall length, the complete plant being some 40 per cent lighter than one employing a separate engine and compressor with an interposed clutch. Higher outputs may be readily obtained by associating a four or a six-cylinder engine with a correspondingly increased number of compressor cylinders.—*February* 13, 1952.

Forthcoming Engagements

Secretaries of Institutions, Societies, &c., desirous of having notices of meetings inserted in this column, are requested to note that, in order to make sure of their insertion, the necessary information should reach this office on, or before, the morning of the Monday of the week preceding the meetings. In all cases the TIME *and* PLACE *at which the meeting is to be held should be clearly stated.*

Association of Supervising Electrical Engineers

To-day, Mar. 7th.—BRISTOL BRANCH: Grand Hotel, Bristol, "Electricity in Agriculture," W. Cover, 7.30 p.m.

Mon., Mar. 10th.—CENTRAL LONDON BRANCH: St. Ermin's Hotel, Caxton Street, S.W.1, "Maintenance and Repair of Electrical Motors," D. R. Reekie, 7 p.m.——N.W. LONDON BRANCH: Prince of Wales Hotel, Kingsbury Road, N.W.9, "Automatic Power Factor Correction," James Orr, 7.45 p.m.

Tues., Mar. 11th.—S.W. LONDON BRANCH: St. George's Hall, 8s. George's Road, Wimbledon, "Voltage Regulators," E. M. Pendrill, 8.15 p.m.

Wed., Mar. 12th.—N. LONDON BRANCH: Three Jolly Butchers Hotel, Wood Green, Address by H. E. J. Butler, 8.15 p.m.——BIRMINGHAM BRANCH: Chamber of Commerce, New Street, Birmingham, "Installation Practice," W. J. Parker, 7 p.m.

Fri., Mar. 14th.—CREWE BRANCH: Crewe Arms Hotel, Crewe, "Factory Electrical Maintenance," C. Maddocks, 7.30 p.m.——LIVERPOOL BRANCH: Laboratories of Applied Electricity, Liverpool University, Brownlow Street, Liverpool, 3, "The Cathode Ray Oscillograph as a Tool," R. C. Turnock, 7.30 p.m.——NOTTINGHAM BRANCH: Electricity Showrooms, Smithy Row, Nottingham, "Auto Electrical Equipment," F. Bull, 7.30 p.m.

Sat., Mar. 15th.—OXFORD BRANCH: Southern Electricity Board, George Street, Oxford, "Television," 3 p.m.

British Institution of Radio Engineers

Thurs., Mar. 13th.—SCOTTISH SECTION: The University, Drummond Street, Edinburgh, "Radar as an Aid to Navigation," N. J. Donald, 7 p.m.

Fri., Mar. 14th.—SCOTTISH SECTION: Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, "The Future of Broadcasting," Paul Adorian, 7 p.m.

Engineers' Guild

Thurs., Mar. 13th.—Caxton Hall, Westminster, London, S.W.1, "The Problem of the Over Forty's," L. N. Duguid, 6 p.m.

Illuminating Engineering Society

To-day, Mar. 7th.—HUDDERSFIELD GROUP: Electricity Showrooms, Market Street, Huddersfield, "Railway Signalling," G. G. F. Halliwell, 7.15 p.m.

Tues., Mar. 11th.—Lighting Service Bureau, 2, Savoy Hill, London, W.C.2, "The Lighting of Shipyards," J. S. McCulloch, 6 p.m.

Wed., Mar. 12th.—EDINBURGH CENTRE: Lighting and Cleansing Department, 357, High Street, Edinburgh, Short Papers and Annual General Meeting, 7 p.m.

Thurs., Mar. 13th.—LEICESTER CENTRE: E. Midlands Electricity Board, Charles Street, Leicester, "Sports Lighting," M. W. Peirce, 6.30 p.m.——MANCHESTER CENTRE: Town Hall Extension, Manchester, "The Performance of Vehicle Headlights on the Road," A. G. Harris, 6 p.m.

Fri., Mar. 14th.—BIRMINGHAM CENTRE: Imperial Hotel, Temple Street, Birmingham, Annual General Meeting, "The Physical Principles Governing Fittings Design," W. H. Willott, 6 p.m.

Incorporated Plant Engineers

Mon., Mar. 10th.—DUNDEE BRANCH: Mathers Hotel, Dundee, Annual General Meeting, 7.30 p.m.

Tues., Mar. 11th.—E. LANCS BRANCH: Engineers' Club, Albert Square, Manchester, Annual General Meeting, 7.15 p.m.——GLASGOW BRANCH: Engineering Centre, 351, Sauchiehall Street, Glasgow, Annual General Meeting and General Discussion, 7 p.m.——S. WALES BRANCH: Institute of Engineers, Park Place, Cardiff, "High and Low Temperature Insulation Materials," 7.15 p.m.

Wed., Mar. 12th.—EDINBURGH BRANCH: 25, Charlotte Square, Edinburgh, Annual General Meeting, 7 p.m.

Thurs., Mar. 13th.—KENT BRANCH: Queen's Head Hotel, Maidstone, "Illumination and Factory Lighting," 7 p.m.——NEWCASTLE UPON TYNE BRANCH: Roadway House, Oxford Street, Newcastle upon Tyne, Annual General Meeting, 7.30 p.m.

Institute of British Foundrymen

Wed., Mar. 12th.—LANCASHIRE BRANCH: Engineers' Club, Albert Square, Manchester, "A System of Studying Castings Defects," G. W. Nicholls and D. T. Kershaw, 7 p.m.

Institute of Industrial Supervisors

Wed., Mar. 12th.—WEST BROMWICH SECTION: Grammar School, West Bromwich, "The Manufacture of Glass," R. E. Bastick, 7.45 p.m.

Thurs., Mar. 13th.—COVENTRY SECTION: Craven Arms Hotel, High Street, Coventry, "Pattern Making and Foundry Work," 7.30 p.m.——SMETHWICK SECTION: Chance Technical College, Crocketts Lane, Smethwick, "Patent Law," 7.30 p.m.

Institute of Marine Engineers

Tues., Mar. 11th.—85–88, The Minories, London, E.C.3, "Epicyclic Gears," H. N. G. Allen and T. P. Jones, 5.30 p.m.

Institute of Metals

Mon., Mar. 10th.—SCOTTISH LOCAL SECTION: Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, Annual General Meeting, "Joining Metals," J. C. Chaston, 6.30 p.m.

Institute of Petroleum

Wed., Mar. 12th.—26, Portland Place, London, W.1, "Alcohol Motor Fuels: Production and Use," S. J. W. Pleeth; "Economic Aspects of Alcohol in Motor Fuels," T. C. Owtram, 5.30 p.m.

Institute of Road Transport Engineers

Mon., Mar. 10th.—SCOTTISH CENTRE: North British Hotel, Edinburgh, "The Servicing of the Diesel Engine," S. Parrish, 7.30 p.m.

Tues., Mar. 11th.—WESTERN GROUP: Grand Hotel, Bristol, "Diesel Engine Repair and Maintenance, and Workshop Practice," R. M. May, 7.30 p.m.

Wed., Mar. 12th.—E. MIDLANDS CENTRE: Mechanics Institute, Nottingham, "Electricity as Applied to P.S. and H.G. Vehicles," 7.30 p.m.

Fri., Mar. 14th.—S. WALES GROUP: Institute of Engineers, Park Place, Cardiff, "Rear Axles," R. H. Wilson, 7 p.m.

Institution of Chemical Engineers

Sat., Mar. 8th.—MIDLANDS BRANCH: The University, Edmund Street, Birmingham, "Liquid/Liquid Extraction in Laboratory and Pilot Plant," J. F. Short and P. Eagliesfield, 3 p.m.

Mon., Mar. 10th.—MIDLAND CENTRE GRADUATES' AND STUDENTS' SECTION: The University, Edmund Street, Birmingham, "The Good Life for a Chemical Engineer," W. N. Hoyte, 6.30 p.m.

Tues., Mar. 11th.—Geological Society, Burlington House, Piccadilly, London, W.1, "The Pneumatic Conveying of Solids," D. M. Newitt, G. F. Hillyar Russ and R. H. Clark, 5.30 p.m.

Fri., Mar. 14th.—N.E. CENTRE GRADUATES' AND STUDENTS' SECTION: Stephenson Building, Claremont Road, Newcastle upon Tyne, Annual Meeting, followed by Technical Films, 6.15 p.m.

Institution of Civil Engineers

Tues., Mar. 11th.—Great George Street, Westminster, London, S.W.1, "The Impact of Radioactivity on Public Health Engineering Services," A. Key and A. W. Kenny, 5.30 p.m.

Thurs., Mar. 13th.—MIDLANDS ASSOCIATION: James Watt Memorial Institute, Great Charles Street, Birmingham, "The Structural Design of Modern Aircraft," S. C. Redshaw, 6 p.m.

Institution of Electrical Engineers

To-day, Mar. 7th.—N.E. STUDENTS' SECTION: Grey Hall, King's College, Newcastle upon Tyne, "Some Experiments on Heat Transfer in Fluids," B. E. Western, 6.30 p.m.

Mon., Mar. 10th.—Savoy Place, London, W.C.2, Discussion on "Remote Measurement and Instrumentation," opened by H. Horwood, 5.30 p.m.

Wed., Mar. 12th.—RADIO SECTION: Savoy Place, London, W.C.2, "The Slot Aerial and its Application to Aircraft," and "A Survey of External and Suppressed Aircraft Aerials for Use in the High-Frequency Band," R. H. J. Cary, 5.30 p.m.——SCOTTISH CENTRE: Heriot-Watt College, Edinburgh, "The Dimming of Low-Pressure Discharge Lamps," C. E. Williams, 7 p.m.——N. MIDLAND CENTRE: Town Hall, Barnsley, "A Review of Research in the Electricity Supply Industry," C. W. Marshall, 7 p.m.

Thurs., Mar. 13th.—Savoy Place, London, W.C.2, "Electronic Telephone Exchanges," T. H. Flowers, 5.30 p.m.——N. MIDLAND CENTRE: Town Hall, Leeds, "Sound Recording—Home, Professional, Scientific and Industrial Applications," G. F. Dutton, 7 p.m.

Institution of Engineering Inspection

Tues., Mar. 11th.—Technical College, Coventry, "Precision Measurements," J. H. Hobbs, 7.30 p.m.

Wed., Mar. 12th.—N.W. BRANCH: Engineers' Club, Albert Square, Manchester, Presentation of Films by G. W. Pekarek, 7.30 p.m.

Institution of Engineers and Shipbuilders in Scotland

Tues., Mar. 11th.—39, Elmbank Crescent, Glasgow, "Considering Dredging Craft," D. W. Low, 6.30 p.m.

Fri., Mar. 14th.—University College, Dundee, "Higher Tensile Short-Link Steel Chain and Chain Slings," W. Gibson Biggart, 7.15 p.m.

Institution of Mechanical Engineers

To-day, Mar. 7th.—Storey's Gate, St. James's Park, London, S.W.1, "The Use of Heavy Fuels for Medium-Sized Marine and Stationary Diesel Engines," J. R. P. Smith, 5.30 p.m.——N.E. BRANCH, GRADUATES' SECTION: Northern Gas Board Showrooms, Grainger Street, Newcastle upon Tyne, "Operation and Testing of Steam Turbine Governors," G. C. Jain, 7 p.m.——SCOTTISH BRANCH: Robert Gordon's College, Aberdeen, "Some Fuel and Power Projects," H. Roxbee Cox, 7.30 p.m.

Tues., Mar. 11th.—AUTOMOBILE DIVISION: Storey's Gate, St. James's Park, London, S.W.1, "Shock Absorbers," J. W. Kinchin and C. R. Stock, 5.30 p.m.——S. WALES BRANCH: Mackworth Hotel, Swansea, Lecture on the Welding Report of the Anglo-American Productivity Council, 6 p.m.

Wed., Mar. 12th.—SOUTHERN BRANCH: University College, Southampton, "Ship Research," S. Livingston Smith, 7 p.m.——LONDON GRADUATES' SECTION: Institution of Civil Engineers, Great George Street, S.W.1, Debate, "The Railways no Longer Fulfil Inter-Urban Requirements and Therefore Should be Replaced by Trunk Roads and Aerodromes," 6 p.m.

Thurs., Mar. 13th.—N.W. BRANCH: Engineers' Club, Albert Square, Manchester, "Some Fuel and Power Projects," H. Roxbee Cox, 6.45 p.m.——SCOTTISH BRANCH, GRADUATES' SECTION: Royal Technical College, Glasgow, Annual General Meeting, Chairman's Address, "Practical Applications of Photoelasticity," Ian W. Mitchell, 6.30 p.m.——YORKSHIRE BRANCH: The University, Leeds, "The Design and Development of Boilers for the Catering Industry," C. W. Mustill, 7 p.m.

Fri., Mar. 14th.—Storey's Gate, St. James's Park, London, S.W.1, "Basic Engineering Standards and Their Place in Design," G. C. Adams, 5.30 p.m.——N.E. BRANCH GRADUATES' SECTION: Head, Wrightson and Co., Ltd., Teesdale Ironworks, Thornaby-on-Tees, "Water Power," C. W. D. Carradice, 7 p.m.

Institution of Post Office Electrical Engineers

Tues., Mar. 11th.—Institution of Electrical Engineers, Savoy Place, London, W.C.2, "The Control of External Major Works," E. A. Scholey, 5 p.m.

Institution of Production Engineers

To-day, Mar. 7th.—SOUTHERN SECTION: Polygon Hotel, Southampton, annual general meeting, 7.30 p.m.——W. WALES SECTION: Central Library, Alexandra Road, Swansea, "Corby Iron and Steel Works of Stewarts and Lloyds, Ltd.," E. A. Taylor, 7.30 p.m.

Mon., Mar. 10th.—SHEFFIELD SECTION: Royal Victoria Station Hotel, Sheffield, Annual General Meeting, 6.30 p.m.

Tues., Mar. 11th.—DUNDEE SECTION: Mathers Hotel, Whitehall Crescent, Dundee, "Modern Applied Metrology," G. U. Stabler, 7.45 p.m.

Wed., Mar. 12th.—N. IRELAND SECTION: Municipal College of Technology, Belfast, "The Jig Boring Machine as a Production Tool," W. J. Sayers, 7.30 p.m.——NOTTINGHAM SECTION: Welbeck Hotel, Milton Street, Nottingham, "Employee Remunerations and Incentives," R. B. Simpson, 7.15 p.m.——PRESTON SECTION: The Bull and Royal, Church Street, Preston, "The Co-ordination of Production Engineering and Cost Accounting," D. Mayman, 7.15 p.m.

Thurs., Mar. 13th.—LONDON SECTION: Royal Empire Society, Northumberland Avenue, W.C.2, Annual General Meeting, 6.45 p.m., "Resistance Welding—A Scientific Mass Production Assembly Process," A. J. Hipperson, 7 p.m.——ROCHESTER AND DISTRICT SECTION: Rotary Room, Sun Hotel, Chatham, "The Legal Side of Production Engineering," H. Peter Jost, 7.30 p.m.

Fri., Mar. 14th.—EASTERN COUNTIES SECTION: Public Library, Ipswich, Annual General Meeting, 6.30 p.m., "Practical Gear Production," L. Westley Smith, 7.30 p.m.——STOKE-ON-TRENT SECTION: Technical College, Cauldon Place, Stoke-on-Trent, Annual General Meeting, "Selection and Training of Foremen," W. H. R. Dalley, 7 p.m.

Institution of Structural Engineers

Wed., Mar. 12th.—LANCASHIRE AND CHESHIRE BRANCH: The Temple, 24, Dale Street, Liverpool, "The Britannia Tubular Bridge over the Menai Straits," J. Cunningham, 6 p.m.

Thurs., Mar. 13th.—11, Upper Belgrave Street, London, S.W.1, "Faults in Concrete Structures," P. G. Bowie, 5.55 p.m.

Junior Institution of Engineers

To-day, Mar. 7th.—39, Victoria Street, London, S.W.1, "The History of the Aviation Engine," F. R. Banks, 6.30 p.m.

Manchester Association of Engineers

To-day, Mar. 7th.—Engineers' Club, Albert Square, Manchester, "Tubular Structures," E. McMinn, 6.45 p.m.

Newcomen Society

Wed., Mar. 12th.—Institution of Mechanical Engineers, Storey's Gate, St. James's Park, S.W.1, "Development of Postal Franking Machines," A. R. J. Ramsey, 5.30 p.m.

North-East Coast Institution of Engineers and Shipbuilders

To-day, Mar. 7th.—Mining Institute, Neville Hall, Newcastle upon Tyne, "Concerning Steam Turbines for Marine Use," J. Brown, 6.15 p.m.

Royal Aeronautical Society

Tues., Mar. 11th.—GRADUATES' AND STUDENTS' SECTION: 4, Hamilton Place, London, W.1, "An Introduction to Supersonics," C. H. E. Warren, 7.30 p.m.

Women's Engineering Society

Mon., Mar. 10th.—LONDON BRANCH: 35, Grosvenor Place, S.W.1, "Co-operation—Professional Institutions and Trades Unions," 7 p.m.

Thurs., Mar. 13th.—MANCHESTER BRANCH: Engineers' Club, Albert Square, Manchester, "The Lost Wax Process of Precision Casting," F. H. Davis, 6.30 p.m.

Contracts

VICKERS-ARMSTRONGS, Ltd., has received an order from Jörgen P. Jensen, of Norway, for a motor tanker of 25,000 tons deadweight, which is the third vessel of this size for the same owner. The ship will be 565ft length between perpendiculars by 80ft moulded breadth by 42ft 6in depth and will be built at the company's naval yard at Newcastle upon Tyne and propelled, at a service speed of 13 knots, by a Vickers-Doxford oil engine of 6600 b.h.p., constructed at the Barrow-in-Furness works.

ALEXANDER STEPHEN AND SONS, Ltd., has received orders from the P. and O. Steam Navigation Company for two cargo liners of 11,500 tons deadweight and one of 10,500 tons deadweight. The larger vessels will be driven at a service speed of 18 knots by single-screw turbine machinery of 13,000 s.h.p. and the third vessel will have double-reduction geared turbines and a service speed of 16 knots.

PACKAGING EDUCATIONAL COURSE.—The fourth educational course on packaging, organised by the Institute of Packaging, is to be held at Shell-Mex House, Strand, London, W.C.2, from May 19th to 23rd. Full particulars of it are available from the Institute at 20-21, Took's Court, Cursitor Street, London, E.C.4.